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(54) Title: ABRASIVE ARTICLE, METHOD OF MANUFACTURE OF SAME, METHOD OF USING SAME FOR FINISHING, AND A PRODUCTION TOOL
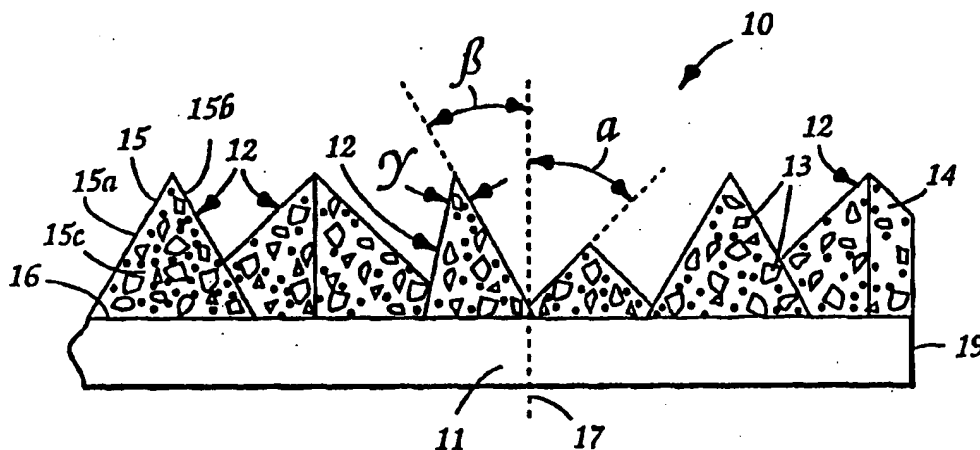
(57) Abstract

An abrasive article (10) is provided having a sheet-like structure having a major surface (16) having deployed in fixed position thereon a plurality of abrasive three-dimensional abrasive composites (12), each of the composites comprising abrasive particles dispersed in a binder (14) and having a precise shape defined by a distinct and discernible boundary (15) that includes specific dimensions, wherein the precise shapes are not all identical. The invention also relates to methods for manufacturing such an abrasive article (10), including the production tool and production tool master used in the scheme of manufacturing the abrasive article (10).

ABRASIVE ARTICLE, METHOD OF MANUFACTURE
OF SAME, METHOD OF USING SAME FOR FINISHING,
AND A PRODUCTION TOOL

5   ## TECHNICAL FIELD
        This invention relates to an abrasive article
having a sheet-like structure having a major surface
having deployed thereon a plurality of abrasive
composites having precise shapes, wherein the precise
10 shapes are not all identical. The invention also
relates to methods of manufacturing an abrasive
article, and a production tool used to manufacture such
an abrasive article, and a method of using such an
abrasive article to reduce a surface finish.
15

                     ## BACKGROUND ART
        In general, abrasive articles employ a plurality
of abrasive particles which are bonded together as a
unitary structure (e.g., a grinding wheel) or bonded
20 separately to a common backing (e.g., a coated abrasive
article). While these types of abrasive articles have
been utilized to abrade and finish workpieces for many
years, problems remain in the field.
        For instance, one persistent problem confronting
25 the abrasive industry arises from the generally inverse
relationship associated between the cut rate (i.e., the
amount of workpiece removed for a given time interval)
and the finish that is imparted by the abrasive article
on the workpiece surface. That is, it is difficult to
30 design an abrasive article that affords a relatively
high rate of cut while concomitantly imparting a
relatively fine surface finish on the workpiece being
abraded. This explains the presence of a wide range of
abrasive products in the market using coarse grit
35 (i.e., relatively large particle size of abrasive
particles) to fine grit (i.e., relatively small

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particle size of abrasive particles). The use of these
differently grit-sized abrasive products in a separate
and sequential manner can provide some measure of
success in ultimately achieving both a high cut and a
5   fine finish, but the practice can be cumbersome and
time consuming. Naturally, a single abrasive article
which simultaneously would provide both high cut rate
and fine finish would be more convenient and highly
desired in the industry.

10   In addition to these goals, it has also been
desired in the abrasive industry to provide an abrasive
article which imparts a consistent surface finish in
the workpiece while lessening or preventing scribing
and/or chatter. Scribing refers to the occurrence of
15   pronounced unwanted grooves in the workpiece surface
which results in an increase in surface roughness units
(Ra). Ra is the arithmetic average of the scratch
depth. Typically, the grooves, when they occur, extend
in the surface of the workpiece in a direction tracking
20   the relative motion of the abrasive article vis-a-vis
the workpiece surface. On the other hand, chatter means
an undesirable repetive pattern created on the surface
of a workpiece, usually at regular spaced intervals at
a direction perpendicular to the direction of belt
25   movement.

        While various attempts have been made to create
new and improved abrasive products, no complete
solution to the problems noted above have been
presented. While the following list of references
30   describe a variety of abrasive products none is known
to provide a completely satisfactory result to these
problems.

        More specifically, U.S. Patent No. 2,115,897
(Wooddell et al.) teaches an abrasive article having a
35   backing and attached thereto by an adhesive are a
plurality of blocks of bonded abrasive material. These

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bonded abrasive blocks can be adhesively secured to the backing in a specified pattern.

U.S. Patent No. 2,242,877 (Albertson) teaches a method of making a compressed abrasive disc. The

5   method involves embedding abrasive particles in a binder layer that is coated on a fibrous backing. Then, a mold die is used to impart a molded pattern or contour into the thickness of binder and particle layer under heat and pressure to form a compressed abrasive

10   disc. The molded surface of the abrasive disc has a specified working surface pattern which is the inverse of the profile of the molding die.

U.S. Patent No. 2,755,607 (Haywood) teaches a coated abrasive in which there are land and groove

15   abrasive portions, which can form, for example, an overall rectlinear or serpentine pattern. An adhesive coat is applied to the front surface of a backing and this adhesive coat is then combed to create peaks and valleys to pattern the surface of the adhesive coat.

20   Haywood discloses that each of the lands and grooves formed in the adhesive coat by such a combing procedure preferably have the same width and thickness, but that they may be varied. Next the abrasive grains are distributed uniformly in the lands and grooves of the

25   previously patterned adhesive coat followed by solidification of the adhesive coat. The abrasive particles used in Haywood are individual grains which are not used in slurry form with other grains in a binder. Therefore, the individual abrasive grains have

30   irregular non-precise shapes.

U.S. Patent No. 3,048,482 (Hurst) discloses an abrasive article comprising a backing, a bond system and abrasive granules that are secured to the backing by the bond system. The abrasive granules are a

35   composite of abrasive grains and a binder which is separate from the bond system. The abrasive granules

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are three dimensional and are preferably pyramidal in
shape. To make this abrasive article, the abrasive
granules are first made via a molding process. Next, a
backing is placed in a mold, followed by the bond
5 system and the abrasive granules. The mold has
patternized cavities therein which results in the
abrasive granules having a specified pattern on the
backing.

U.S. Patent No. 3,605,349 (Anthon) pertains to a
10 lapping type abrasive article. The binder and the
abrasive grain are mixed together and then sprayed onto
the backing through a grid. The presence of the grid
results in a patterned abrasive coating.

Great Britain Patent Application No. 2,094,824
15 (Moore) pertains to a patterned lapping film. The
abrasive slurry is prepared and the slurry is applied
through a mask to form discrete islands. Next, the
resin or binder is cured. The mask can be a silk
screen, stencil, wire, or a mesh.

20 U.S. Patent No. 4,644,703 (Kaczmarek et al.)
concerns a lapping abrasive article comprising a
backing and an abrasive coating adhered to the backing.
The abrasive coating further comprises a suspension of
lapping size abrasive grains and a binder cured by free
25 radical polymerization. The abrasive coating can be
shaped into a pattern by a rotogravure roll.

U.S. Patent No. 4,773,920 (Chasman et al.)
concerns a lapping abrasive article comprising a
backing and an abrasive coating adhered to the backing.
30 The abrasive coating comprises a suspension of lapping
size abrasive grains and a binder cured by free radical
polymerization. The abrasive coating can be shaped
into a pattern by a rotogravure roll.

U.S. Patent No. 4,930,266 (Calhoun et al.) teaches
35 a patterned abrasive sheeting in which the abrasive
granules are strongly bonded and lie substantially in a

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plane at a predetermined lateral spacing. In this
invention the abrasive granules are applied via a
impingement technique so that each granule is
essentially individually applied to the abrasive
5 backing. This results in an abrasive sheeting having a
precisely controlled spacing of the abrasive granules.

U.S. Patent No. 5,014,468 (Ravipati et al.)
pertains to a lapping film intended for ophthalmic
applications. The lapping film comprises a patterned
10 surface coating of abrasive grains dispersed in a
radiation cured adhesive binder. The patterned surface
coating has a plurality of discrete raised three
dimensional formations having widths which diminish in
the direction away from the backing. To make the
15 patterned surface, an abrasive slurry is applied to a
rotogravure roll to provide a shapes surface which is
then removed from the roll surface and then the
radiation curable resin is cured.

U.S. Patent No. 5,015,266 (Yamamoto) pertains to
20 an abrasive sheet by uniformly coating an abrasive
adhesive slurry over an embossed sheet. The resulting
abrasive coating has high and low abrasive portions
formed by the surface tension of the slurry,
corresponding to the irregularities of the base sheet.
25   U.S. Patent No. 5,107,626 (Mucci) teaches a method
of providing a patterned surface on a substrate by
abrading with a coated abrasive containing a plurality
of precisely shaped abrasive composites. The abrasive
composites are in a non-random array and the abrasive
30 composites comprise a plurality of abrasive grains
dispersed in a binder.

U.S. Patent No. 5,152,917 (Pieper et al.)
discloses a coated abrasive article that provides both
a relatively high rate of cut and a relatively fine
35 surface finish on the workpiece surface. The
structured abrasive of Pieper et al. involves precisely

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shaped abrasive composites that are bonded to a backing
in a regular nonrandom pattern. The consistency of the
profile of the abrasive composites provided by the
abrasive strucutre of Pieper et al., among other
5 things, helps provide a consistent surface finish in
the worked surface.

Japanese Patent Application No. S63-235942
published March 23, 1990 teaches a method of a making a
lapping film having a specified pattern. An abrasive
10 slurry is coated into a network of indentations in a
tool. A backing is then applied over the tool and the
binder in the abrasive slurry is cured. Next, the
resulting coated abrasive is removed from the tool.
The binder can be cured by radiation energy or thermal
15 energy.

Japanese Patent Application No. JP 4-159084
published June 2, 1992 teaches a method of making a
lapping tape. An abrasive slurry comprising abrasive
grains and an electron beam curable resin is applied to
20 the surface of an intaglio roll or indentation plate
having a network of indentations. Then, the abrasive
slurry is exposed to an electron beam which cures the
binder and the resulting lapping tape is removed from
the roll.

25   United States patent application No. 07/820,155
filed 13 January 1992 (Calhoun), which is commonly
assigned to the owner of the present application,
teaches a method of making an abrasive article. An
abrasive slurry is coated into recesses of an embossed
30 substrate. The resulting construction is laminated to
a backing and the binder in the abrasive slurry is
cured. The embossed substrate is removed and the
abrasive slurry adheres to the backing.

U.S. Patent No. 5,219,462 (Bruxvoort et al.)
35 teaches a method for making an abrasive article. An
abrasive slurry is coated substantially only into the

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recesses of an embossed backing. The abrasive slurry
comprises a binder, abrasive grains and an expanding
agent. After coating, the binder is cured and the
expanding agent is activated. This causes the slurry
5   to expand above the surface of the embossed backing.

     United States patent application No. 08/004,929
filed 14 January 1993 (Spurgeon et al.), which is
commonly assigned to the owner of the present
application, teaches a method of making an abrasive
10 article. In one aspect of this patent application, an
abrasive slurry is coated into recesses of an embossed
substrate. Radiation energy is transmitted through the
embossed substrate and into the abrasive slurry to cure
the binder.

15   United States patent application No. 08/067,708
filed 26 May 1993 (Mucci et al.), which is commonly
assigned to the owner of the present application,
teaches a method of polishing a workpiece with a
structured abrasive. The structured abrasive comprises
20 a plurality of precisely shaped abrasive composites
bonded to a backing. During polishing, the structured
abrasive oscillates.

     The use of variable pitch sawing teeth has been
disclosed as a cutting edge for a hack saw blade, such
25 as mentioned in a trade advertisement distributed by
Lenox Co. and entitled "Lenox Hackmaster V Vari-Tooth
Power Hack Saw Blades", to provide balanced cutting
action and quiet performance. This hack saw blade
design is described as useful to saw metal bar stock,
30 ganged workpieces, or work with holes, slots or
interruptions. This hack saw blade design is not
specifically disclosed as adaptable for frictional
abrasion applications between two rubbing surfaces
including a complex three-dimensional working surface,
35 nor does the LENOX publication disclose the wherewithal
therefor.

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Although some of the abrasive articles made
according to the aforementioned patents, viz. Pieper et
al., might provide an abrasive article yielding both
high rate of cut and relatively fine finish, it has
5   been observed that scribing can occur in surfaces
worked by some prior art abrasive articles when the
abrasive articles are used. For instance, many abrasive
articles have directional limitations insofar as how
the articles are to be oriented relative to the work
10   surface to be reduced, i.e., some articles cannot be
used omnidirectionally. If used improperly by accident
or neglect, e.g., if such an abrasive article is not
properly aligned with the surface to be worked by the
operator, these abrasive articles, among other things,
15   can cause scribing in the worked surface.

Therefore, it can be understood that the abrasive
industry would highly value a versatile high-cut rate,
fine finish abrasive article which is more resistant to
inadvertent scribing and more adaptable to a wider
20   range of abrasive conditions.

DISCLOSURE OF THE INVENTION

The present invention provides an abrasive article
which has a high cut rate yet imparts a relatively fine
surface finish. The invention provides an abrasive
25   article having a sheet-like structure having a major
surface having deployed thereon a plurality of
precisely shaped abrasive composites, wherein not all
shapes are identical. The invention also provides
methods of manufacturing the abrasive article, a
30   production tool useful in such methods, and a methods
of using the abrasive article to reduce surface finish.

In one embodiment, this invention relates to an
abrasive article having a sheet-like structure having a
major surface having deployed in fixed position thereon
35   a plurality of abrasive three-dimensional abrasive
composites, each of the composites comprising abrasive

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particles dispersed in a binder and having a
substantially precise shape defined by a substantially
distinct and discernible boundary which includes
substantially specific dimensions, wherein the precise
5   shapes are not all identical.

In a further embodiment, substantially all of the
aforesaid abrasive composites exist as pairs, each pair
including two unmatched abrasive composites, one
abrasive composite having a nonidentical shape to an
10   adjacent abrasive composite.

Yet another embodiment of this invention relates
to an abrasive article wherein the aforesaid abrasive
composites include a first abrasive composite having a
first precise shape having specific first dimensions
15   and a second abrasive composite having a second precise
shape and second specific dimensions wherein the first
and the second specific dimensions are nonidentical.

In a further embodiment of the abrasive article of
the invention, the aforesaid first and second abrasive
20   composites each has a boundary defined by at least four
planar surfaces wherein adjacent planar surfaces meet
to define an edge of a certain length, wherein at least
one edge of the first composite has a length which is
different from the length of all edges of the second
25   composite. In one further embodiment, the length of the
at least one edge of the first composite has a length
which varies with respect to the length of any edge of
the second composite in a ratio between 10:1 to 1:10,
not inclusive of 1:1.

30   In another embodiment of the abrasive article of
the invention, the aforesaid first and second abrasive
composites have a first and second geometrical shape,
respectively, which are nonidentical. For example, the
aforesaid first and second geometrical shapes can be
35   selected from different members of the group of
geometrical shapes consisting of cubic, prismatic,

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conical, truncated conical, cylindrical, pyramidal, and truncated pyramidal.

In another embodiment of the abrasive article of the invention, each abrasive composite has a boundary

5 defined by at least four planar surfaces wherein adjacent planar surfaces meet at an edge to define an angle of intersection therebetween, wherein at least one angle of intersection of the the first abrasive composite is different from all of the angles of

10 intersection of the second composite. In a preferred embodiment, no angle of intersection of adjacent planar surfaces in the first abrasive composite is equal to 0° or 90°. In a further embodiment thereof, substantially all the abrasive composites have a pyramidal shape.

15 In another preferred embodiment of the invention, the surface of the abrasive article has a machine direction and opposite side edges, each side edge being parallel to the machine direction axis and each side edge being respectively within a first and second

20 imaginary plane each of which is perpendicular to the surface, a plurality of parallel elongate abrasive ridges deployed in fixed position on the surface, each ridge having a longitudinal axis located at its transverse center and extending along an imaginary line

25 which intersects the first and second planes at an angle which is neither 0° nor 90°, and wherein each abrasive ridge comprises a plurality of the aforesaid three-dimensional abrasive composites which are intermittently spaced along the longitudinal axis.

30 In a further embodiment of the abrasive article of the invention, the aforesaid plurality of parallel elongate abrasive ridges are deployed in first and second groups wherein the first and second groups are located at nonoverlapping locations in the in the

35 machine direction or in a direction perpendicular to the machine direction of the major surface, wherein the

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longitudinal axis of at least one abrasive ridge within the first group extends along an imaginary line that intersects with an imaginary line extending from at least one longitudinal axis of an abrasive ridge in the

5 second group.

In yet another embodiment of the abrasive article of the present invention, each abrasive ridge has a distal end spaced from the surface and each distal end extends to a third imaginary plane which is spaced from

10 and parallel to the surface. For example, in one embodiment, the abrasive composites have the same height value measured from the surface to distal end in a range of from about 50 micrometers and about 1020 micrometers.

15 In another preferred embodiment of the abrasive article of the invention, abrasive composites are fixed on the major surface in a density of about 100 to about 10,000 abrasive composites/cm^2. In one further embodiment, substantially the entire surface area of

20 the major surface is covered by the abrasive composites.

In another embodiment of the invention relating to a method for making an abrasive article described herein, a method comprises the steps of:

25 (a) preparing an abrasive slurry wherein the abrasive slurry comprises a plurality of abrasive particles dispersed in a binder precursor;

(b) providing a backing having a front surface
30 and a back surface; and a production tool provided with a plurality of cavities in at least one major surface thereof, each cavity having a precise shape defined by a distinct and discernible boundary which includes
35 specific dimensions, wherein the precise cavity shapes are not all identical;

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(c)   providing a means to apply the abrasive
      slurry into a plurality of the cavities of
      the production tool;

(d)   contacting the front surface of the backing

5   with the production tool such that the
      abrasive slurry wets the front surface;

(e)   solidifying the binder precursor to form a
      binder, whereupon solidification the abrasive
      slurry is converted into a plurality of

10   abrasive composites; and

(f)   separating the production tool from the
      backing after the solidifying to provide a
      plurality of abrasive composites as attached
      to the backing each having a precise shape

15   defined by a distinct and discernable
      boundary which include specific dimensions,
      wherein the precise abrasive composite shapes
      are not all identical.

It is preferred that the six steps are carried out
20 in a continuous manner, thereby providing an efficient
method of making a coated abrasive article.

Alternatively, this method can be practiced where
the abrasive slurry can be applied to the backing
instead of the production tool before contacting of the
25 coated backing with the cavitated side of the
production tool to fill the cavities in same.

In still another embodiment, the abrasive
composite described herein is used in a method to
reduce the surface of a workpiece, having the steps of:

30   (a)   bringing into frictional contact a workpiece
             surface and the above-described abrasive
             article; and

         (b)   moving at least one of said abrasive article
             or said workpiece surface relative to the

35   other such that the surface finish of said
             workpiece surface is reduced.

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In yet another embodiment, the invention relates
to a production tool for making the aforesaid abrasive
article, which comprises a sheet-like structure having
a plurality of cavities formed on a major surface

5 thereof, each cavity having a precise shape defined by
a distinct and discernible boundary which includes
specific dimensions, wherein the precise cavity shapes
are not all identical.

In another embodiment of the invention, there is a

10 method of making a master, and the product of this
method, which can be used to form the aforesaid
production tool, said master having a major surface
extending within a first imaginary plane, comprising
the steps of:

15   (1) determining angles corresponding to facing
right and left planar surfaces of adjacent three-
dimensional shapes and wherein each of said angles has
a value as measured between its planar surface and a
plane which extends in a normal direction to said

20 master surface and contains an edge of said planar
surface in contact with said surface, by the following
substeps:

(i) selecting an angle value between, but not
including, 0° and 90° to establish a first right half

25 angle of a first right planar surface of a first right-
side three-dimensional shape with a random number
generating means capable of randomly selecting an angle
value between, but not including, 0° and 90°;

(ii) selecting an angle value between, but

30 not including, 0° and 90° with said random number
generating means to establish a first left half angle
for a first left planar surface of a first left-side
three-dimensional shape facing said first right planar
surface of said first right-side three-dimensional

35 shape;

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(iii) proceeding along a first direction
extending linearly within said first imaginary plane to
a second left planar surface of a second left-side
three-dimensional shape located adjacent said first
5   left-side three-dimensional shape and using said random
number generating means to select a value between, but
not including, 0° and 90° to establish a second left
planar angle for said second left planar surface;
    (iv) using said random number generating
10 means to select a value between, but not including, 0°
and 90° for a second right planar surface of a second
right-side three-dimensional shape facing said second
left planar surface;
    (v) proceeding along said first direction to
15 a third right-side three-dimensional shape located
adjacent said second right-side three-dimensional
shape;
    (vi) repeating said substeps (i), (ii),
(iii), (iv), and (v), in that sequence, at least once;
20   (2) repeating step (1) except that the angles are
determined for left and right planar surfaces of
adjacent three-dimensional shapes deployed in two
adjacent rows in a second direction extending linearly
within said first imaginary plane, wherein said first
25 and second directions intersect;
        (3) using means to determine, for a given width of
said surface of said master, locations of grooves
required to be cut by a cutting means to form a series
of intersecting grooves defining a plurality of precise
30 three-dimensional shapes having said angles calculated
by steps (1) and (2); and
        (4) providing a cutting means to cut grooves in
said surface of said master in correspondence to said
angles calculated by steps (1) and (2) and said groove
35 locations determined by step (3) to form a series of
intersecting grooves which define a plurality of

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precise three-dimensional shapes upraised from said
surface, each of said precise shapes being defined by a
distinct and discernible boundary including specific
dimensions, wherein not all said three-dimensional
5 shapes are identical. This master can then be used to
form the aforsaid production tool such as by applying a
molten polymer onto the master surface, solidifying the
polymer and removing the production tool having a
surface containing cavities having shapes in counter-
10 correspondence to the projections on the master
surface.

Preferably, in this aspect of the invention, the
right and left half angles of the projections formed in
the master surface each have a value between 8° and 45°
15 and the three-dimensional shapes comprise pyramids.

Other features, advantages, and constructs of the
invention will be better understood from the following
description of figures and the preferred embodiments of
the present invention.

20   **BRIEF DESCRIPTION OF THE DRAWINGS**
Fig. 1 is an end sectional view representing one
embodiment of an abrasive article of this invention.

Fig. 2 is an end sectional view representing
another embodiment of an abrasive article of this
25 invention.

Fig. 3 is a side schematic view showing an
apparatus for making an abrasive article according to
this invention.

Fig. 4 is a side schematic view showing an
30 alternate apparatus for making an abrasive article
according to this invention.

Fig. 5 is a Scanning Electron Microscope (SEM)
photomicrograph taken at 45X of the top surface of an
abrasive article of the invention having 355 micrometer
35 high pyramidal-shaped abrasive composites of varying
dimension.

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Fig. 6 is a SEM photomicrograph taken at 25X of the top surface of a polypropylene production tool of the present invention having about 355 micrometer deep pyramidal-shaped cavities of varying dimensions.

5   Fig. 7 is a plane view in schematic of a production tool of the invention.

Fig. 8 is a schematic plane view of the topography of an abrasive article of the present invention having pyramidal shapes for all the abrasive composites,

10 wherein adjacent shapes have the same height but different side angles.

DETAILED DESCRIPTION

The abrasive article of the invention exhibits a high rate of cut while imparting a relatively level,

15 fine surface finish on the workpiece being abraded and does not readily scribe the workpiece. While not desiring to be bound to any theory at this time, it, is hypothesized that an array of abrasive composites having perfect pitch, i.e., an array of abrasive

20 composites that are all identical in dimensions, may generate a vibrational resonance, whereby the working abrasive article surface may reach a resonant vibration state which can cause surface finish problems, known as chatter marks. In the present invention, it is believed

25 that the variation in the dimensions between adjacent precisely-shaped abrasive composites disrupts and/or prevents such vibrational resonance from developing to thus provide a high cut-rate, fine finish with decreased chatter incidence in addition to decreased

30 scribing.

For purposes of this invention, the expression "precisely-shaped", or the like, as used herein in describing the abrasive composites, refers to abrasive composites having a shape that has been formed by

35 curing the curable binder of a flowable mixture of abrasive particles and curable binder while the mixture

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is both being borne on a backing and filling a cavity
on the surface of a production tool. Such a "precisly
shaped" abrasive composite would thus have precisely
the same shape as that of the cavity. Further, the
5   precise shape of the abrasive composite is defined by
relatively smooth-surfaced sides that are bounded and
joined by well-defined sharp edges having distinct edge
lengths with distinct endpoints defined by the
intersections of the various sides with the proviso
10 that at least one of said abrasive composites has at
least one dimension which is different from that of an
adjacent abrasive composite or composites.

       For purposes of this invention, the term
"boundary", as used herein to define the abrasive
15 composites, means the exposed surfaces and edges of
each abrasive composite that delimit and define the
actual three-dimensional shape of each abrasive
composite. These distinct and discernible boundaries
are readily visible and clear when a cross-section of
20 the abrasive article of the invention is examined under
a microscope such as a scanning electron microscope.
The distinct and discernible boundaries of each
abrasive composite form the cross-sectional outlines
and contours of the precise shapes of the present
25 invention. These boundaries separate and distinguish
one abrasive composite from another even when the
abrasive composites abutt each other along a common
border at their bases. By comparison, in an abrasive
composite that does not have a precise shape, the
30 boundaries and edges are not definitive, e.g., where
the abrasive composite sags before completion of its
curing.

       For purposes of this invention, the term
"dimension", as used in connection with defining the
35 abrasive composites, means a measure of spatial extent
such as an edge length of a side surface (inclusive of

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the base) of the shape associated with an abrasive
composite or, alternatively, the "dimension" can mean a
measure of an angle of inclination of a side surface
extending from the backing. Therefore, for purposes of
5   this invention, a "dimension" that is "different" for
two different abrasive composites, means an edge length
or an angle of intersection made at the meeting edge of
two planar surfaces of a shape of a first abrasive
composite that is nowhere duplicated in value by any of
10 the edge lengths or angles of intersections defining
the shape of a second abrasive composite in the array.
These first and second abrasive composites can be
adjacent in a preferred embodiment.

For purposes of this invention, the terminology
15 "geometrical shape" means a basic category of three-
dimensional regular geometrical shape, such as cubic,
pyramidal, pyrismatic, conical, cylindrical, truncated
pyramidal, truncated conical and the like.

For purposes of this invention, the terminology
20 "adjacent composite" or "adjacent composites", or the
like, as used herein, means at least two neighboring
composites which lack any intervening abrasive
composite structure located on a direct line
therebetween.

25 Referring to Figure 1 for illustrative purposes,
the side view of the abrasive article 10 shows a
backing 11 having a pair of opposite side edges 19 (one
shown), a machine direction axis (not shown) would
extend parallel to the direction of said side edges 19
30 for purposes of this illustration, and a plurality of
abrasive composites 12 fixed to at least the top
surface 16 of the backing. The abrasive composites 12
comprise a plurality of abrasive particles 13 dispersed
in the binder 14. Each abrasive composite has a
35 discernible precise shape. It is preferred that the
abrasive particles do not protrude beyond the planar

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surface planes 15 of the shape before the coated
abrasive article is put into service. As the coated
abrasive article is being used to abrade a surface, the
composite breaks down revealing unused abrasive
5 particles.

        In one aspect of the invention, viz., where the
abrasive composites are spaced-apart at constant pitch
(constant peak- to-peak distance from centers of
adjacent abrasive composites), the "adjacent composite"
10 will involve one nearest neighboring composite or
multiple nearest neighboring composites equidistantly
spaced from the abrasive composite which has the
different dimension thereto. However, in another aspect
of the invention, if the abrasive composites are spaced
15 at a varied pitch, then it is possible, in that
instance, for the "adjacent composite" to involve an
abrasive composite which is not necessarily the closest
composite as spaced from the abrasive composite having
the different dimension thereto, as long as no
20 intervening abrasive structure is located on a direct
line therebetween.

Backing

        A backing can be conveniently used in this
invention to provide a surface for deploying the
25 abrasive composites thereon, wherein such a backing has
a front and back surface and can be any conventional
abrasive backing. Examples of such include polymeric
film, primed polymeric film, cloth, paper, vulcanized
fiber, nonwovens, and combinations thereof. The backing
30 optionally may be a reinforced thermoplastic backing,
such as described in the assignee's co-pending United
States application No. 07/811,547 (Stout et al., filed
20 December 1991) or an endless belt as described in
the assignee's co-pending U.S. application No.
35 07/919,541 (Benedict et al., filed 20 December 1991).
The backing may also contain a treatment or treatments

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to seal the backing and/or modify some physical
properties of the backing. These treatments are well
known in the art.

The backing may also have an attachment means on
5 its back surface to secure the resulting coated
abrasive to a support pad or back-up pad. This
attachment means can be a pressure sensitive adhesive
or a loop fabric for a hook and loop attachment.
Alternatively, there may be a intermeshing attachment
10 system, such as described in the U.S. Patent No.
5,201,101 (Rouser et al.).

The back side of the abrasive article may also
contain a slip resistant or frictional coating. An
example of such a coating include compositions
15 containing an inorganic particulate (e.g., calcium
carbonate or quartz) dispersed in an adhesive. An
antistatic coating comprising materials such as carbon
black or vanadium oxide also may be included in the
abrasive article, if desired.

20 **Abrasive Composite**

a. Abrasive Particles

The abrasive particles typically have a particle
size ranging from about 0.1 to 1500 micrometers,
usually between about 0.1 to 400 micrometers,
25 preferably between 0.1 to 100 micrometers and more
preferably between 0.1 to 50 micrometers. It is
preferred that the abrasive particles have a Mohs'
hardness of at least about 8, more preferably above 9.
Examples of such abrasive particles include fused
30 aluminum oxide (which includes brown aluminum oxide,
heat treated aluminum oxide, and white aluminum oxide),
ceramic aluminum oxide, green silicon carbide, silicon
carbide, chromia, alumina zirconia, diamond, iron
oxide, ceria, cubic boron nitride, boron carbide,
35 garnet, and combinations thereof.

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The term abrasive particles also encompasses when
single abrasive particles are bonded together to form
an abrasive agglomerate. Suitable abrasive
agglomerates for this invention are further described
5 in U.S. Patent Nos. 4,311,489 (Kressner); 4,652,275
(Bloecher et al.) and 4,799,939 (Bloecher et al.).

It is also within the scope of this invention to
have a surface coating on the abrasive particles. The
surface coating may have many different functions. In
10 some instances the surface coatings increase adhesion
to the binder, alter the abrading characteristics of
the abrasive particle, and the like. Examples of
surface coatings include coupling agents, halide salts,
metal oxides including silica, refractory metal
15 nitrides, refractory metal carbides, and the like.

In the abrasive composite there may also be
diluent particles. The particle size of these diluent
particles may be on the same order of magnitude as the
abrasive particles. Examples of such diluent particles
20 include gypsum, marble, limestone, flint, silica, glass
bubbles, glass beads, aluminum silicate, and the like.

        b. Binder

The abrasive particles are dispersed in an organic
binder to form the abrasive composite. The organic
25 binder can be a thermoplastic binder, however, it is
preferably a thermosetting binder. The binder is formed
from a binder precursor. During the manufacture of the
abrasive article, the thermosetting binder precursor is
exposed to an energy source which aids in the
30 initiation of the polymerization or curing process.
Examples of energy sources include thermal energy and
radiation energy which includes electron beam,
ultraviolet light, and visible light. After this
polymerization process, the binder precursor is
35 converted into a solidified binder. Alternatively for
a thermoplastic binder precursor, during the

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manufacture of the abrasive article the thermoplastic
binder precursor is cooled to a degree that results in
solidification of the binder precursor. Upon
solidification of the binder precursor, the abrasive
5 composite is formed.

The binder in the abrasive composite is generally
also responsible for adhering the abrasive composite to
the front surface of the backing. However, it some
instances there may be an additional adhesive layer
10 between the front surface of the backing and the
abrasive composite.

There are two main classes of thermosetting
resins, condensation curable and addition polymerized
resins. The preferred binder precursors are addition
15 polymerized resin because they are readily cured by
exposure to radiation energy. Addition polymerized
resins can polymerize through a cationic mechanism or a
free radical mechanism. Depending upon the energy
source that is utilized and the binder precursor
20 chemistry, a curing agent, initiator, or catalyst is
sometimes preferred to help initiate the
polymerization.

Examples of typical binders precursors include
phenolic resins, urea-formaldehyde resins, melamine
25 formaldehyde resins, acrylated urethanes, acrylated
epoxies, ethylenically unsaturated compounds,
aminoplast derivatives having pendant unsaturated
carbonyl groups, isocyanurate derivatives having at
least one pendant acrylate group, isocyanate
30 derivatives having at least one pendant acrylate group,
vinyl ethers, epoxy resins, and mixtures and
combinations thereof. The term acrylate encompasses
acrylates and methacrylates.

Phenolic resins are widely used in abrasive
35 article binders because of their thermal properties,
availability, and cost. There are two types of

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phenolic resins, resole and novolac. Resole phenolic resins have a molar ratio of formaldehyde to phenol greater than or equal to one to one, typically between 1.5:1.0 to 3.0:1.0. Novolac resins have a molar ratio

5 of formaldehyde to phenol of less than one to one. Examples of commercially available phenolic resins include those known by the tradenames "Durez" and "Varcum" from Occidental Chemicals Corp.; "Resinox" from Monsanto; "Aerofene" from Ashland Chemical Co. and

10 "Aerotap" from Ashland Chemical Co.

Acrylated urethanes are diacrylate esters of hydroxy terminated NCO extended polyesters or polyethers. Examples of commercially available acrylated urethanes include UVITHANE 782, available

15 from Morton Thiokol Chemical, and CMD 6600, CMD 8400, and CMD 8805, available from Radcure Specialties.

Acrylated epoxies are diacrylate esters of epoxy resins, such as the diacrylate esters of bisphenol A epoxy resin. Examples of commercially available

20 acrylated epoxies include CMD 3500, CMD 3600, and CMD 3700, available from Radcure Specialities.

Ethylenically unsaturated resins include both monomeric and polymeric compounds that contain atoms of carbon, hydrogen, and oxygen, and optionally, nitrogen

25 and the halogens. Oxygen or nitrogen atoms or both are generally present in ether, ester, urethane, amide, and urea groups. Ethylenically unsaturated compounds preferably have a molecular weight of less than about 4,000 and are preferably esters made from the reaction

30 of compounds containing aliphatic monohydroxy groups or aliphatic polyhydroxy groups and unsaturated carboxylic acids, such as acrylic acid, methacrylic acid, itaconic acid, crotonic acid, isocrotonic acid, maleic acid, and the like. Representative examples of acrylate resins

35 include methyl methacrylate, ethyl methacrylate styrene, divinylbenzene, vinyl toluene, ethylene glycol

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diacrylate, ethylene glycol methacrylate, hexanediol
diacrylate, triethylene glycol diacrylate,
trimethylolpropane triacrylate, glycerol triacrylate,
pentaerythritol triacrylate, pentaerythritol

5   methacrylate, pentaerythritol tetraacrylate and
pentaerythritol tetraacrylate. Other ethylenically
unsaturated resins include monoallyl, polyallyl, and
polymethallyl esters and amides of carboxylic acids,
such as diallyl phthalate, diallyl adipate, and

10 N,N-diallyladipamide. Still other nitrogen containing
compounds include tris(2-acryloyl oxyethyl)iso-
cyanurate, 1,3,5-tri(2-methyacryloxyethyl)- s-triazine,
acrylamide, methylacrylamide, N-methylacrylamide,
N,N-dimethylacrylamide, N-vinylpyrrolidone, and

15 N-vinylpiperidone.
        The aminoplast resins have at least one pendant
alpha, beta-unsaturated carbonyl group per molecule·or
oligomer. These unsaturated carbonyl groups can be
acrylate, methacrylate, or acrylamide type groups.

20 Examples of such materials include N-hydroxymethyl)-
acrylamide, N,N'-oxydimethylene-bisacrylamide, ortho
and para acrylamidomethylated phenol, acrylamido-
methylated phenolic novolac, and combinations thereof.
Examples of these materials are further described in

25 U.S. Patent No. 4,903,440 (Larson et al.) and U.S.
Patent No. 5,236,472 (Kirk et al.).
        Isocyanurate derivatives having at least one
pendant acrylate group and isocyanate derivatives
having at least one pendant acrylate group are further

30 described in U.S. Patent 4,652,274 (Boettcher et al.).
The preferred isocyanurate material is a triacrylate of
tris(hydroxy ethyl) isocyanurate.
        Epoxy resins have an oxirane and are polymerized
by the ring opening. Such epoxide resins include

35 monomeric epoxy resins and oligomeric epoxy resins.
Examples of some preferred epoxy resins include

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2,2-bis[4- (2,3-epoxypropoxy)-phenyl propane]
(diglycidyl ether of bisphenol A) and commercially
available materials under the trade designation "Epon
828", "Epon 1004", and "Epon 1001F" available from
5   Shell Chemical Co., "DER-331", "DER-332", and "DER-334"
available from Dow Chemical Co. Other suitable epoxy
resins include glycidyl ethers of phenol formaldehyde
novolac (e.g., "DEN-431" and "DEN-428" available from
Dow Chemical Co.).
10   The epoxy resins of the invention can polymerize
via a cationic mechanism with the addition of an
appropriate cationic curing agent. Cationic curing
agents generate an acid source to initiate the
polymerization of an epoxy resin. These cationic
15 curing agents can include a salt having an onium cation
and a halogen containing a complex anion of a metal or
metalloid. Other cationic curing agents include a salt
having an organometallic complex cation and a halogen
containing complex anion of a metal or metalloid which
20 are further described in U.S. Patent 4,751,138 (Tumey
et al.)(column 6, line 65 to column 9, line 45).
Another example is an organometallic salt and an onium
salt is described in U.S. Patent 4,985,340 (Palazzotto)
(column 4 line 65 to column 14 line 50); European
25 Patent Applications 306,161 and 306,162. Still other
cationic curing agents include an ionic salt of an
organometallic complex in which the metal is selected
from the elements of Periodic Group IVB, VB, VIB, VIIB
and VIIIB which is described in European Patent
30 Applications 109,851.
     Regarding free radical curable resins, in some
instances it is preferred that the abrasive slurry
further comprise a free radical curing agent. However
in the case of an electron beam energy source, the
35 curing agent is not always required because the
electron beam itself generates free radicals.

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Examples of free radical thermal initiators
include peroxides, e.g., benzoyl peroxide, azo
compounds, benzophenones, and quinones. For either
ultraviolet or visible light energy source, this curing
5   agent is sometimes referred to as a photoinitiator.
Examples of initiators, that when exposed to
ultraviolet light generate a free radical source,
include but are not limited to those selected from the
group consisting of organic peroxides, azo compounds,
10 quinones, benzophenones, nitroso compounds, acryl
halides, hydrozones, mercapto compounds, pyrylium
compounds, triacrylimidazoles, bisimidazoles,
chloroalkytriazines, benzoin ethers, benzil ketals,
thioxanthones, and acetophenone derivatives, and
15 mixtures thereof. Examples of initiators that when
exposed to visible radiation generate a free radical
source, can be found in U.S. Patent No. 4,735,632
(Oxman et al.), entitled Coated Abrasive Binder
Containing Ternary Photoinitiator System. The
20 preferred initiator for use with visible light is
"Irgacure 369" commercially available from Ciba Geigy
Corporation.

The weight ratios between the abrasive particles
and binder can range between 5 to 95 parts abrasive
25 particles to 5 to 95 parts binder; more typically, 50
to 90 parts abrasive particles and 10 to 50 parts
binder.

c. Additives

The abrasive slurry can further comprise optional
30 additives, such as, for example, fillers (including
grinding aids), fibers, lubricants, wetting agents,
thixotropic materials, surfactants, pigments, dyes,
antistatic agents, coupling agents, plasticizers, and
suspending agents. The amounts of these materials are
35 selected to provide the properties desired. The use of
these can affect the erodability of the abrasive

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composite. In some instances an additive is purposely added to make the abrasive composite more erodable, thereby expelling dulled abrasive particles and exposing new abrasive particles.

5   Examples of useful fillers for this invention include: metal carbonates (such as calcium carbonate {such as chalk, calcite, marl, travertine, marble and limestone}, calcium magnesium carbonate, sodium carbonate, magnesium carbonate), silica {such as
10 quartz, glass beads, glass bubbles and glass fibers} silicates {such as talc, clays, montmorillonite, feldspar, mica, calcium silicate, calcium metasilicate, sodium aluminosilicate, sodium silicate}, metal sulfates {such as calcium sulfate, barium sulfate,
15 sodium sulfate, aluminum sodium sulfate, aluminum sulfate}, gypsum, vermiculite, wood flour, aluminum trihydrate, carbon black, metal oxides {such as calcium oxide or lime, aluminum oxide, titanium oxide}, and metal sulfites {such as calcium sulfite}.

20   The term filler also encompasses materials that are known in the abrasive industry as grinding aids. A grinding aid is defined as particulate material that the addition of which has a significant effect on the chemical and physical processes of abrading which
25 results in improved performance. Examples of chemical groups of grinding aids include waxes, organic halide compounds, halide salts and metals and their alloys. The organic halide compounds will typically break down during abrading and release a halogen acid or a gaseous
30 halide compound. Examples of such materials include chlorinated waxes like tetrachloronaphtalene, pentachloronaphthalene; and polyvinyl chloride. Examples of halide salts include sodium chloride, potassium cryolite, sodium cryolite, ammonium cryolite,
35 potassium tetrafluoroboate, sodium tetrafluoroborate, silicon fluorides, potassium chloride, magnesium

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chloride. Examples of metals include, tin, lead, bismuth, cobalt, antimony, cadmium, iron, and titanium. Other miscellaneous grinding aids include sulfur, organic sulfur compounds, graphite, and metallic

5   sulfides.

Examples of antistatic agents include graphite, carbon black, vanadium oxide, humectants, and the like. These antistatic agents are disclosed in U.S. Patent Nos. 5,061,294 (Harmer et al.); 5,137,542 (Buchanan et

10 al.), and 5,203,884 (Buchanan et al.).

A coupling agent can provide an association bridge between the binder precursor and the filler particles or abrasive particles. Examples of coupling agents include silanes, titanates, and zircoaluminates. The

15 abrasive slurry preferably contains anywhere from about 0.01 to 3% by weight coupling agent.

An example of a suspending agent is an amorphous silica particle having a surface area less than 150 meters square/gram that is commercially available from

20 DeGussa Corp., under the trade name "OX-50".

Abrasive Composite Shape

Each abrasive composite has a precise shape associated with it. The precise shape is delimited by a distinct and discernible boundary, these terms being

25 defined hereinabove. These distinct and discernible boundaries are readily visible and clear when a cross-section of the abrasive article of the invention is examined under a microscope such as a scanning electron microscope, e.g., as shown in Figure 5. The distinct

30 and discernible boundaries of each abrasive composite form the outline or contour of the precise shapes of the present invention. These boundaries separate and distinguish one abrasive composite from another even when the abrasive composites abutt each other along a

35 common border at their bases.

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In comparison, in an abrasive composite that does
not have a precise shape, the boundaries and edges are
not definitive, e.g., where the abrasive composite sags
before completion of its curing. Thus, the expression
5   "precisely-shaped", or the like, as used herein in
describing the abrasive composites, also refers to
abrasive composites having a shape that has been formed
by curing the curable binder of a flowable mixture of
abrasive particles and curable binder while the mixture
10 is both being borne on a backing and filling a cavity
on the surface of a production tool. Such a precisly
shaped abrasive composite would thus have precisely the
same shape as that of the cavity. These cavities in a
production tool are depicted in Figure 6.
15   A plurality of such composites provide three-
dimensional shapes that project outward from the
surface of the backing in an inverse pattern to that
presented by the production tool. Each composite is
defined by a well-defined boundary or perimeter, the
20 base portion of the boundary being the interface with
the backing to which the precisely shaped composite is
adhered. The remaining portion of the boundary is
defined as the inverse shape of the cavity in the
surface of the production tool in which the composite
25 is cured. The entire outer surface of the composite is
confined, either by the backing or by the cavity,
during its formation. Suitable methods and techniques
for forming precisely-shaped composites are disclosed
in U.S. Patent No. 5,152,917 (Pieper et al.).
30   This invention departs from U.S. Patent No.
5,152,917 (Pieper et al.), however, insofar as the
provision of differing dimensioned shapes, among other
things, in the array of abrasive composites. This
proviso can be established by any convenient approach,
35 e.g., by arbitrarily assigning at least one dimensional
variance, such as defined.hereinbelow, between adjacent

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composite shapes in a portion or the whole of the array
of composites for an abrasive article. An array of
grooves can be formed in a surface of a master tool,
e.g., by use of a diamond turning machine, from which

5 is produced a production tool having an array of cavity
shapes, which, in turn, can receive and mold an
abrasive slurry described herein, which are the inverse
shape of the predetermined array of abrasive composite
shapes. Alternatively, as described herein, a copy of a

10 desired pattern of variably dimensioned shapes of
abrasive composites can be formed in the surface of a
so-called metal master, e.g., aluminum, copper, bronze,
or a plastic master such as acrylic plastic, either of
which can be nickel-plated after grooving, as by

15 diamond turning grooves to leave upraised portions
corresponding to the desired predetermined shapes of
the abrasive composites. Then, flexible plastic
production tooling ean be formed, in general, from the
master by a method explained in U.S. Patent No.

20 5,152,917 (Pieper et al). As a result, the plastic
production tooling has a surface which includes
indentations having the inverse shape of the abrasive
composites to be formed therewith. Alternatively, the
metal master can be manufactured by diamond turning

25 grooves to leave the desired shapes in a metal surface
which is amenable to diamond turning, such as aluminum,
copper or bronze, and then nickel plating the grooved
surface to provide the metal master. Exemplary
techniques for making the varying dimensioned abrasive

30 composites will be described in greater detail
hereinbelow.

Regarding the construction of the abrasive
composites per se, referring to Figure 1 for
illustrative purposes, the abrasive composite 12 has a

35 boundary 15. The boundary or boundaries associated
with the shape result in one abrasive composite being

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physically separated to some extent from another
adjacent abrasive composite. To form an individual
abrasive composite, a portion of the boundaries forming
the shape of the abrasive composite must be separated

5 from one another. Note that in Figure 1, the base or a
portion of the abrasive composite closest to the
backing can abutt with an adjacent abrasive composite.
Referring to Figure 2, the abrasive article 20 of the
invention comprises a backing 21 having a plurality of

10 abrasive composites 22 bonded to the backing. The
abrasive composites comprises a plurality of abrasive
particles 23 that are dispersed in a binder 24. In
this aspect of the invention, there are open spaces 25
between adjacent composites. It is also within the

15 scope of this invention to have a combination of
abrasive composites bonded to a backing in which some
of adjacent abrasive composites abutt, while other ,
adjacent abrasive composites have open spaces between
them.

20   In some instances, e.g., pyramidal non-cylindrical
shapes, the boundaries forming the sides of the shape
also are planar. For such shapes that have multiple
planes, there are at least four planes (inclusive of
three sides and the bottom or base). The number of

25 planes for a given shape can vary depending upon the
desired geometry, for instance the number of planes can
range from four to over 20. Generally, there are
between four to ten planes, preferably between four to
six planes. These planes intersect to form the desired

30 shape and the angles at which these planes intersect
will determine the shape dimensions. Referring to
Figure 1, the abrasive composite 12 has a boundary 15
which is planar. The side planes 15A and 15b intersect
at an angle γ, with cross-section 15C facing the viewer

35 and is coplanar with the page.

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A key aspect of this invention is that at least
one the abrasive composites has a different dimension
from another abrasive composite in the array.
Preferably, the different dimension is established
5 between at least one pair of adjacent composites, and
even more preferably, established for each and every
pair of adjacent composites provided on the surface of
the abrasive article. The terminology of "every pair"
of adjacent composites encompasses an arbitrary
10 consideration of every composite on the surface of the
abrasive article as paired with its adjacent composite.
In general, at least 10% of the pairs of adjacent
composites have a different dimension therebetween,
preferably at least 30%, more preferably at least 50%.
15 Most preferably, substantially 100% of the abrasive
composites have a different dimension from its
respective paired adjacent abrasive composite. The
result of this proviso of different dimensions between
abrasive composites, viz. between adjacent pairs of
20 abrasive composites, results in an abrasive article
that produces a relatively finer surface finish on the
workpiece being abraded or refined. Since the
dimensions of adjacent abrasive composites vary, there
is a reduced tendency for scribed grooves to be
25 imparted by the precisely abrasive composites into the
workpiece surface. In general, if less than 10% of the
pairs of abrasive composites have an adjacent composite
that has a different dimension, the effect of the
invention of decreasing scribing while achieving high-
30 cut rates and fine finishes may not be satisfactorily
realized. In general, the number of pairs of adjacent
abrasive composites that have different dimensions is
selected to minimize or reduce scribing. The percentage
of the total abrasive composites that this number of
35 pairs represents will depend upon several factors such
as the workpiece type, abrading interface pressure,

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abrasive article rotation speed and other typical
abrading conditions.

It is within the scope of this invention to have
some, but never all, of the abrasive composites present
5 on the surface which have identical shapes. However,
the abrasive composites having identical shapes, if
present, preferably should not be located directly
adjacent to or next to one another in order to fully
realize the benefits of the invention. For instance,
10 two abrasive composites in the abrasive article may
have shapes defined by same dimensions, but,
preferably, the two abrasive composites should be
separated from one another in the array of composites
by at least one intervening abrasive composite that
15 differs in a dimension from each.

There must be at least one dimension associated
with at least one of the abrasive composites that is
different from another abrasive composite. However, it
also is within the scope of this invention that there
20 are two or more different dimensions therebetween.
These dimensions can be varied in a variety of ways,
such as by providing a different length of an edge at
the intersection of two planar surfaces of a shape of a
composite; by providing a different angle formed at the
25 meeting edge of two adjacent planar surfaces of a shape
of a composite; or by providing different types of
geometrical shapes for the abrasive composites to
provide either a different edge length and/or a
different angle.
30   If an edge length is varied to provide the
different dimension for purposes of the invention, in
one embodiment, the length or dimensions of the edges
in composites, particularly adjacent composites, each
having a pyramidal shape as the geometrical shape and a
35 common height of between 25 and 1020 micrometers,
generally can differ from at least about 1 to about 500

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micrometers, and more preferably between 5 to 250
micrometers. In one embodiment, the length of the at
least one edge of a first composite in the array has a
length which varies with respect to the length of any
5 edge of a second composite in a ratio between 10:1 to
1:10, not inclusive of 1:1, and preferably as between
two adjacent composites.

More generally, the abrasive composite shape of
this invention can be any convenient shape, but it is
10 preferably a three-dimensional regular geometric shape
such as a cubic, prismatic (e.g., triangular,
quadrilateral, hexagonal, etc.), conical, truncated
conical (flat top), cylindrical, pyramidal, truncated
pyramidal (flat top) and the like. The geometrical
15 shape of adjacent abrasive composites can be varied,
e.g. pyramidal next to prismatic, in order to provide
the requisite dimensional variance therebetween. In one
embodiment of the invention, the shapes of the abrasive
composites, e.g., pyramidal, all are provided with the
20 same total height value, measured from the backing, in
a range of from about 50 micrometers to about 1020
micrometers.

A preferred geometrical shape is a pyramid and the
pyramid can be a four or five side sided (inclusive of
25 the base) pyramid. In one preferred embodiment, all
composite shapes are pyramidal. Even more preferably,
the dimensional variance is achieved between adjacent
pyramidal-shaped composites by varying the angle formed
by a side surface with the backing in adjacent
30 pyramids. For example, angles α and β formed by the
sides of adjacent pyramidal shaped composites, such as
depicted in Figure 1, are different angles from each
other and each have a value of between 0° and 90° (i.e.
non-inclusive of 0° and 90°). Preferably, the angle α
35 or β formed between a side surface of the pyramidal-
shaped composites and an imaginary plane 17 (Figure 1)

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extending normal to the intersection of the respective
side surface and the backing should be greater than or
equal to 8°, but less than or equal to 45°. From a
practical standpoint, angles less than 8° may release
5   cured composite shapes from the production tool with
greater difficulty. On the other hand, angles greater
than 45° may unduly enlarge the spacing between
adjacent abrasive composites such that insufficient
abrading surfaces are provided over the area of the
10 backing.

It also is preferable to select angles for α and β
wherein each have a value between 0° and 90° and which
differ in magnitude by at least about 1°, and more
preferably at least about 5°.

15   It is also preferred to form pyramidal shapes for
the abrasive composites where two side surfaces of each
pyramid meet at the apex of each pyramid to form a
material-included angle γ (see Figure 1) in a cross-
sectional view of the pyramid having a value of greater
20 than or equal to 25° and less than or equal to 90°. The
lower value of 25° may be a practical limit since it
can be difficult to form a peak or apex shape for an
abrasive composite which is sharp and less than 25°
with the slurry and production tool methodology
25 described herein. To more fully realize the benefits
of the invention, this proviso with respect to
material-included angle γ should be used together with
the above-mentioned proviso that intervening angles α
and β between adjacent composites be provided as
30 different and randomly selected between 0° and 90° as
explained hereinabove.

Further, in any individual abrasive composite, the
angles made by the various surface planes with the
backing do not necessarily have to be the same for a
35 given composite. For instance in a four sided pyramid
(one base and three side surfaces), the angles formed

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by any of the first, second and third side planes with
the backing can be different from each other.
Naturally, the angle at which the side surfaces
intersect with each other will also vary as the angle
5   formed between the side surface and the backing are
varied.

        Also, in the embodiment of this invention where
the dimensional variance between adjacent composites is
established by varying side surface angles between
10 adjacent abrasive composites, such as angles α and β
(Figure 1), it is preferred that the respective angles
chosen for each of α and β between adjacent composites
are not repeated and constant throughout the array of
abrasive composites, which is believed to even further
15 ensure no resonance is created between the workpiece
and the abrasive article. Therefore, it is more
desirable to permit and provide different values for
each of α and β between 0° and 90° as one proceeds from
one pair adjacent composites to the next immediate pair
20 of adjacent composites along either the widthwise or
lengthwise direction of the abrasive article (e.g., see
Figure 8). This change in the values of α and β between
different sets of adjacent composites in the array can
be effected in any convenient manner, such as by
25 randomly picking the values for each of α and β between
the range 0 and 90 degrees.

        For example, if α, as the right half angle (Figure
1), can be randomly selected in the range of between 0°
and 90° for an abrasive composite in one row of
30 composites, then β, as the left half angle facing α, is
randomly chosen for the adjacent abrasive composite in
the adjacent row of composites; and then, as one
preceeds to the next pair of adjacent abrasive
composites in either the widthwise or lengthwise
35 direction along the rows of composites in the array, a
new β, as left half angle, is randomly selected between

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0° and 90° degrees and then a new value for α, as the
facing right half angle, of the adjacent composite can
be randomly selected in the range of 0° to 90° degrees,
and so forth throughout the array. This practice is
5   desirable in order to provide a more uniform
distribution of angles between 0° and 90° degrees
throughout the array of abrasive composites in the
article.

The actual selection of the angles α and β, and γ,
10   throughout the array of abrasive composites, randomly
and subject to the preferred constraints described
herein, can be accomplished in any convenient manner,
for example, by systematic random selections of angle
values by draw within the preferred numerical
15   constraint mentioned herein. These systematic
selections for an array, can be facilitated and
expedited by using a common computer, e.g. a desktop
computer, using the angle constraints described herein
to delimit the range of angle values from which the
20   computer makes a random choice. Algorithms for
selection of random numbers are generally known in the
statistical and computer fields, and have been adapted
to this aspect of the invention. For instance, the well
known linear congruential method for generating
25   pseudorandom numbers can be applied towards randomly
selecting the angles α and β. The application and
implementation of random number generation for
selecting angles for the side faces of the abrasive
composite shapes in the present application is
30   exemplified in the computer source code described in
the APPENDIX hereinafter.

In any event, the angle values, once so selected
for the abrasive composites in the array, can be used
to determine and predicate the pattern and shapes of
35   indentations formed by a diamond turning machine in the
surface of a metal production tool or production tool,

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which, in turn, can be used to make the abrasive
composite articles of the invention by methods
described herein.

In some instances it is preferred to have the
5 height and geometrical shape of all the composites as
the same. This height is the distance of the abrasive
composite from the backing to its outermost point
before the abrasive article is used. If the height and
shape are constant, it is then preferred to have the
10 angle between planes vary.

In order to achieve a fine surface finish on the
workpiece, it is also preferred that the peaks of the
abrasive composites do not align in a column which is
parallel to the abrading direction performed in the
15 machine direction. If the abrasive composite peaks
align in a column parallel to the abrading direction,
this tends to result in grooves imparted to the
workpiece and a coarser surface finish. Thus, it is
preferred that the abrasive composites be offset from
20 one another to prevent this alignment.

In general there are at least 5 individual
abrasive composites per square centimeter. In some
instances, there may be at least about 100 individual
abrasive composites/square centimeter or higher, and
25 more preferably, about 2,000 to 10,000 abrasive
composites/square centimeter. There is no operational
upper limit on the density of the abrasive composites;
although, from a practical standpoint, at some point it
may not be possible to increase the cavity density
30 and/or form precisely shaped cavities in the surface of
the production tooling preferably used to make the
array of abrasive composites. In general, this number
of abrasive composites result in an abrasive article
that has a relatively high rate of cut, a long life,
35 but also results in a relatively fine surface finish on
the workpiece being abraded. Additionally, with this

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number of abrasive composites there is a relatively low
unit force per each abrasive composite. In some
instances, this can result in better, more consistent,
breakdown of the abrasive composite.

5 **Method of Making the Abrasive Article**

        Although additional details will be described
later herein on the methods of making the abrasive
article of the invention, in general, the first step in
making the abrasive article is to prepare an abrasive
10 slurry. The abrasive slurry is made by combining
together by any suitable mixing technique the binder
precursor, the abrasive particles, and the optional
additives. Examples of mixing techniques include low
shear and high shear mixing, with high shear mixing
15 being preferred. Ultrasonic energy may also be
utilized in combination with the mixing step to lower
the abrasive slurry viscosity. Typically, the abrasive
particles are gradually added into the binder
precursor. The amount of air bubbles in the abrasive
20 slurry can be minimized by pulling a vacuum during the
mixing step, for example, by employing conventional
vacuum-assisted methods and equipment.

        In some instances it is preferred to heat,
generally in the range of 30 to 70°C, the abrasive
25 slurry to lower the viscosity. It is important the
abrasive slurry have a rheology that coats well and in
which the abrasive particles and other fillers do not
settle.

        If a thermosetting binder precursor is employed,
30 the energy source can be thermal energy or radiation
energy depending upon the binder precursor chemistry.
If a thermoplastic binder precursor is employed the
thermoplastic is cooled such that it becomes solidified
and the abrasive composite is formed. Other more
35 detailed aspects of the method(s) to make the abrasive
article of the invention will be described hereinbelow.

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Production Tool

A production tool is important, from both practical and technological standpoints, in making an abrasive article of the invention, especially in view
5 of the relatively small sizes of the abrasive composites. The production tool contains a plurality of cavities. These cavities are essentially the inverse shape of the abrasive composite desired and are responsible for generating the shape of the abrasive
10 composites. The dimensions of the cavities are selected to provide the desired shape and dimensions of the abrasive composites. If the shape or dimensions of the cavities are not properly fabricated, the resulting production tool will not provide the desired dimensions
15 for the abrasive composites.

The cavities can be present in a dot like pattern with spaces between adjacent cavities or the cavities can abutt against one another. The cavities butt up against one another to facilitate release of the shaped
20 and cured abrasive slurry. Additionally, the shape of the cavities is selected such that the cross-sectional area of the abrasive composite decreases in the direction away from the backing.

In a more preferred embodiment of the production
25 tool, the production tool has two opposing parallel side edges bounding an array of cavities so configured to provide differing dimensions in the shapes of adjacent abrasive composites formed therewith by methods described herein over a distinct segment of
30 length of the abrasive article, in either a length and/or width direction of the abrasive article, and then this predetermined pattern of differing composite shapes can be repeated at least once more or repeatedly along the length and/or width of the abrasive article,
35 if desired and convenient.

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For example, Figure 7 is a top view representation
of a production tool 70 that can be used to make an
abrasive article of the invention. The side edges 71 of
the production tool are parallel to the machine
5   direction (not shown) of the production tool and are
perpendicular to the transverse width direction of the
production tool. Cavitites 74 are delimited by
intersecting upraised portions represented by solid
lines 72 and 73. The production tool has six distinct
10   groups A, B, C, D, E and F of cavities, wherein in each
group the cavities are aligned in parallel rows bounded
by upraised portions 72, wherein the upraised portions
72 and 73 are the nondeformed (noncavitated) remainder
of the tooling sheet. These groups A-E are arranged
15   head-to-tail along the length of the tooling, as shown
in Figure 7. The rows of cavities in each group that
are aligned most closely with side edges 71 trace   ,
imaginary lines extending at non-parallel (nonzero)
angles to the machine direction of the production tool,
20   and which angles differ from group A to group B to
group C, and so forth up to group F. The angles of the
rows of cavities (and intervening upraised portions 72)
made with the side edges 71 should be established as
between 0° to 90°. Scribing problems can arise at
25   either 0° or 90° angles for rows of cavities with the
side edges 71. Preferably, angles of 5° to 85° are
selected for the angles of the rows of cavities with
the machine direction more assuredly avoid scribing
problems.
30   The angles of the rows of cavities preferably
alternate between clockwise and counterclockwise
directionality from group to group, as shown in Figure
7. The angle formed between rows of cavities and
upraised portions 72 and the side edges 71 can be
35   selected to be the same or different in absolute
magnitude from set to set.

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An abrasive article formed with production tool 70
by methods described herein will have an array of
abrasive composites formed in the inverse shape to the
surface profile presented by the array of cavities in
5   the production tool, such production tool 70. By
arranging rows of cavities at angles in the production
tooling by means of arrangements such as exemplified in
Figure 7, scribing effects can be minimized in the
abrasive article made thereby.

10   Alternatively, the cavities in the production tool
can be arranged to be laterally offset, i.e.,
nonaligned, from one another in the direction advancing
parallel to the side edges of the production tool
(nondepicted). That is, this embodiment provides an
15 optional manner of forming an array of abrasive
composites and intervening grooves which are not
arranged in rows which extend parallel to the the side
edges of the abrasive article. Instead, the abrasive
composites are staggered from each other and non-
20 aligned when viewed from the front of the abrasive
article into the direction parallel to the side edges
of the abrasive article.

The production tool can be a belt, a sheet, a
continuous sheet or web, a coating roll such as a
25 rotogravure roll, a sleeve mounted on a coating roll,
or die. The production tool can be composed of metal,
(e.g., nickel), metal alloys (e.g., nickel alloys),
plastic (e.g., polypropylene, an acrylic plastic), or
any other conveniently formable material. The metal
30 production tool can be fabricated by any conventional
technique such as engraving, hobbing, electroforming,
diamond turning, and the like.

A thermoplastic production tool can be made by
replication off a metal master tool. The metal master
35 will have the inverse pattern desired for the
production tool. The metal master can be made with the

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same basic techniques useful in directly making the
production tool, e.g., by diamond turning a metal
surface. In the event of use of a metal master, a
thermoplastic sheet material can be heated and
5   optionally along with the metal master such that the
thermoplastic material is embossed with the surface
pattern presented by the metal master by pressing the
two surfaces together. The thermoplastic can also be
extruded or cast onto to the metal master and then
10 pressed. The thermoplastic material is cooled to
solidify and produce the production tool. Examples of
preferred thermoplastic production tool materials
include polyester, polycarbonates, polyvinyl chloride,
polypropylene, polyethylene and combinations thereof.
15   Alternatively, a plastic production tool can be
directly made, without the need of a master by
engraving or diamond turning a predetermined array pf
cavities, which have the inverse shape of the abrasive
composites desired, into a surface of the plastic
20 sheet. If a thermoplastic production tool is utilized,
then care must be taken not to generate excessive heat,
particularly during the solidifying step, that may
distort the thermoplastic production tool. Other
suitable methods of production tooling and metal
25 masters are discussed in commonly assigned U.S. Patent
Application No. 08/004,929 (Spurgeon et al.), filed 14
December 1993.
For example, a preferred method of making a
polymeric production tool of the invention of the type
30 depicted in Figure 7 involves the use of a nickel-
plated metal master configured in a drum form. Several
flat sections of nickel-plated master, each about 30
centimeters in length, with the varied shapes of
indentations corresponding to the shapes desired for
35 the abrasive composites are provided in a surface
thereof, are produced by diamond turning with the aid

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of a computer directing the cutting action performed by
the diamond turning machine. These sections of metal
master are welded together head-to-tail, with the
grooves of section being at a non-zero angle to the
5 grooves of the next adjacent section. This chain of
sections is then fixed to a drum so that the composites
are continuous around the circumference of the drum.
Care should be taken to minimize any weld seams from
distending out from between the sections and at the
10 point of joining. The production tool is cast by
extruding polymeric resin onto the drum and passing the
extrudant between a nip roll and the drum, and then
cooling the extrudant to form a production tool in
sheet form having an array of cavities formed on the
15 surface thereof in inverse correspondence to the
surface indentations presented by the master on the
drum. This process can be conducted continuously to,
produce a polymeric tool of any desired length.
Energy Sources
20   When the abrasive slurry comprises a thermosetting
binder precursor, the binder precursor is cured or
polymerized. This polymerization is generally
initiated upon exposure to an energy source. Examples
of energy sources include thermal energy and radiation
25 energy. The amount of energy depends upon several
factors such as the binder precursor chemistry, the
dimensions of the abrasive slurry, the amount and type
of abrasive particles and the amount and type of the
optional additives. For thermal energy, the
30 temperature can range from about 30 to 150°C, generally
between 40 to 120°C. The time can range from about 5
minutes to over 24 hours. The radiation energy sources
include electron beam, ultraviolet light, or visible
light. Electron beam radiation, which is also known as
35 ionizing radiation, can be used at an energy level of
about 0.1 to about 10 Mrad, preferably at an energy

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level of about 1 to about 10 Mrad. Ultraviolet
radiation refers to non-particulate radiation having a
wavelength within the range of about 200 to about 400
nanometers, preferably within the range of about 250 to
5 400 nanometers. It is preferred that 300 to 600
Watt/inch (120-240 Watt/cm) ultraviolet lights are
used. Visible radiation refers to non-particulate
radiation having a wavelength within the range of about
400 to about 800 nanometers, preferably in the range of
10 about 400 to about 550 nanometers. It is preferred that
300 to 600 Watt/inch (120-240 Watt/cm) visible lights
are used.

One method to make the abrasive article of the
invention is illustrated in Figure 3. Backing 41
15 leaves an unwind station 42 and at the same time the
production tool 46 leaves an unwind station 45.
Cavities (not depicted) formed in the upper surface of
production tool 46 are coated and filled with an
abrasive slurry by means of coating station 44.
20 Alternatively, coating station 44 can be relocated to
deposit the slurry on backing 41 instead of the
production tool before reaching drum 43 and the same
ensuing steps are followed as used for coating the
production tooling as described below. Either way, it
25 is possible to heat the abrasive slurry (not shown)
and/or subject the slurry to ultrasonics prior to
coating to lower the viscosity. The coating station
can be any conventional coating means such as drop die
coater, knife coater, curtain coater, vacuum die coater
30 or a die coater. During coating the formation of air
bubbles should be minimized. The preferred coating
technique uses a vacuum die coater, which can be of the
type such as described in U.S. Patent Nos. 3,594,865;
4,959,265 and 5,077,870. After the production tool is
35 coated, the backing and the abrasive slurry are brought
into contact by any means such that the abrasive slurry

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wets the front surface of the backing. In Figure 3,
the abrasive slurry is brought into contact with the
backing by means of contact nip roll 47, and contact
nip roll 47 forces the resulting construction against
5 support drum 43. Next, any convenient form of energy
48 is transmitted into the abrasive slurry that is
adequate to at least partially cure the binder
precursor. The term partial cure is meant that the
binder precursor is polymerized to such a state that
10 the abrasive slurry does not flow from an inverted test
tube. The binder precursor can be fully cured once it
is removed from the production tool by any energy
source. The production tool is rewound on mandrel 49
so that the production tool can be reused again.
15 Additionally, abrasive article 120 is wound on mandrel
121. If the binder precursor is not fully cured, the
binder precursor can then be fully cured by either time
and/or exposure to an energy source. Additional steps
to make the abrasive article according to this first
20 method is further described in U.S. Patent No.
5,152,917 (Pieper et al.) or the above-mentioned U.S.
Patent Application No. 08/004,929 (Spurgeon et al.).
Other guide rolls are used where convenient and are
designated rolls 40.
25   Relative to this first method, it is preferred
that the binder precursor is cured by radiation energy.
The radiation energy can be transmitted through the
production tool or backing so long as the production
tool or backing does not appreciably absorb the
30 radiation energy. Additionally, the radiation energy
source should not appreciably degrade the production
tool. It is preferred to use a thermoplastic
production tool and ultraviolet or visible light.
        As mentioned above, in a variation of this first
35 method, the abrasive slurry can be coated onto the
backing and not into the cavities of the production

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tool. The abrasive slurry coated backing is then
brought into contact with the production tool such that
the abrasive slurry flows into the cavities of the
production tool. The remaining steps to make the
5   abrasive article are the same as detailed above.

A second method for making the abrasive article is
illustrated in Figure 4. The production tool 55 is
provided in the outer surface of a drum, e.g., as a
sleeve which is secured around the circumference of a
10 drum in separate sheet form (e.g., as a heat-shrunk
nickel form) in any convenient manner. Backing 51
leaves an unwind station 52 and the abrasive slurry is
coated into the cavities of the production tool 55 by
means of the coating station 53.   The abrasive slurry
15 can be coated onto the backing by any technique such as
drop die coater, roll coater, knife coater, curtain
coater, vacuum die coater, or a die coater. Again, it
is possible to heat the abrasive slurry and/or subject
the slurry to ultrasonics prior to coating to lower the
20 viscosity. During coating the formation of air bubbles
should be minimized. Then, the backing and the
production tool containing the abrasive slurry are
brought into contact by a nip roll 56 such that the
abrasive slurry wets the front surface of the backing.
25 Next, the binder precursor in the abrasive slurry is at
least partially cured by exposure to an energy source
57. After this at least partial cure, the abrasive
slurry is converted to an abrasive composite that is
bonded or adhered to the backing. The resulting
30 abrasive article 59 is stripped and removed from the
production tool at nip rolls 58 and wound onto a rewind
station 60. In this method, the energy source can be
thermal energy or radiation energy. If the energy
source is either ultraviolet light or visible light,
35 the backing should be transparent to ultraviolet or
visible light. An example of such a backing is

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polyester backing. Other guide and contact rolls can be
used where convenient and are designated rolls 50.

In another variation of this second method, the
abrasive slurry can be coated directly onto the front
5   surface of the backing by moving coating station 53 to
a location upstream from roll 56. The abrasive slurry
coated backing is then brought into contact with the
production tool such that the abrasive slurry wets into
the cavities of the production tool. The remaining
10 steps to make the abrasive article are the same as
detailed above.

After the abrasive article is made, it can be
flexed and/or humidified prior to converting. The
abrasive article can be converted into any desired form
15 such as a cone, endless belt, sheet, disc, etc. before
the abrasive article is put into service.

Method of Refining a Workpiece Surface

Another embodiment of this invention pertains to a
method of refining a workpiece surface. This method
20 involves bringing into frictional contact the abrasive
article of this invention with a workpiece. The term
refine means that a portion of the workpiece is abraded
away by the abrasive article. Additionally, the
surface finish associated with the workpiece surface is
25 reduced after this refining process. One typical
surface finish measurement is Ra; Ra is the arithmetic
surface finish generally measured in microinches or
micrometers. The surface finish can be measured by a
profilometer, such as that available under the trade
30 designation Perthometer or Surtronic.

Workpiece

The workpiece can be any type of material such as
metal, metal alloy, exotic metal alloy, ceramic, glass,
wood, wood like material, composites, painted surface,
35 plastic, reinforced plastic, stone, and combinations
thereof. The workpiece may be flat or may have a shape

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or contour associated with it. Examples of workpieces
include glass ophthalmic lenses, plastic ophthalmic
lenses, glass television screens, metal automotive
components, plastic components, particle board, cam
5 shafts, crank shafts, furniture, turbine blades,
painted automotive components, magnetic media, and the
like.

Depending upon the application, the force at the
abrading interface can range from about 0.1 kg to over
10 1000 kg. Generally this range is between 1 kg to 500
kg of force at the abrading interface. Also depending
upon the application, there may be a liquid present
during abrading. This liquid can be water and/or an
organic compound. Examples of typical organic
15 compounds include lubricants, oils, emulsified organic
compounds, cutting fluids, soaps, or the like. These
liquids may also contain other additives such as
defoamers, degreasers, corrosion inhibitors, or the
like. The abrasive article may oscillate at the
20 abrading interface during use. In some instances, this
oscillation may result in a finer surface on the
workpiece being abraded.

An abrasive composite having an adjacent abrasive
composite with a different dimension attributes to this
25 relatively fine surface finish. Since a portion of the
abrasive composites have different dimensions, the
abrasive composites may not perfectly align in a row
from the perspective of the apices of pyramidal shapes
and the like. For example, Figure 8 includes a
30 representative topographical top view (and side views)
of an abrasive article 85 of the invention wherein an
abrasive composite therein is designated 80 having a
face 82 and apex 81. As seen in Figure 8, the pyramidal
shapes, as a whole, align in rows, and therefore, the
35 apices of the abrasive composites are aligned
irrespective of the differences in side dimensions

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between adjacent abrasive composites facing each other
across common grooves. This arrangement results in
scratches imparted into the workpiece by the abrasive
composites which are continuously crossed over. This
5   continuous crossing of previous scratches results, in
the aggregate, in the finer surface finish.

The abrasive article of the invention can be used
by hand or used in combination with a machine. At
least one or both of the abrasive article and the
10 workpiece is moved relative to the other. The abrasive
article can be converted into a belt, tape rolls, disc,
sheet, and the like. For belt applications, the two
free ends of an abrasive sheet are joined together and
a splice is formed. It is also within the scope of
15 this invention to use a spliceless belt. Generally the
endless abrasive belt traverses over at least one idler
roll and a platen or contact wheel. The hardness of
the platen or contact wheel is adjusted to obtain the
desired rate of cut and workpiece surface finish. The
20 abrasive belt speed ranges anywhere from about 150 to
5000 meters per minute, generally between 500 to 3000
meters per minute. Again this belt speed depends upon
the desired cut rate and surface finish. The belt
dimensions can range from about 5 mm to 1 meter wide
25 and from about 5 cm to 10 meters long. Abrasive tapes
are continuous lengths of the abrasive article. They
can range in width from about 1 mm to 1 meter,
generally between 5 mm to 25 cm. The abrasive tapes
are usually unwound, traverse over a support pad that
30 forces the tape against the workpiece and then rewound.
The abrasive tapes can be continuously feed through the
abrading interface and can be indexed. The abrasive
disc, which also includes what is known in the abrasive
art as "daisies", can range from about 50 mm to 1 meter
35 in diameter. Typically abrasive discs are secured to a
back-up pad by an attachment means. These abrasive

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discs can rotate between 100 to 20,000 revolutions per
minute, typically between 1,000 to 15,000 revolutions
per minute.

The features and advantages of the present

5   invention will be further illustrated by the following
non-limiting examples. All parts, percentages, ratios,
etc, in the examples are by weight unless otherwise
indicated.

Experimental Procedure

10   The following abbreviations are used throughout:

TMPTA: trimethylol propane triacrylate;

TATHEIC: triacrylate of tris(hydroxy ethyl)
        isocyanurate;

PH2:   2-benzyl-2-N,N-dimethylamino-

15   1-(4-morpholinophenyl)-1-butanone, commercially
        available from Ciba Geigy Corp. under the trade
        designation "Irgacure 369";

ASF: amorphous silica filler, commercially available
        from DeGussa under the trade designation

20   "OX-50";

FAO: fused heat treated aluminum oxide;

WAO: white fused aluminum oxide; and

SCA: silane coupling agent, 3-methacryloxy-
        propyltrimethoxysilane, commercially available

25   from Union Carbide under the trade designation
        "A-174".

General Procedure for Making the Abrasive Article

An abrasive slurry was prepared that contained
20.3 parts TMPTA, 8.7 parts TATHEIC, 0.3 parts PH2, 1

30 part ASF, 1 part SCA and 69 parts of grade P-320 FAO.
The slurry was mixed for 20 minutes at 1200 rpm using a
high shear mixer.

The production tool was a continuous web made from
a polypropylene sheet material commercially available

35 from Exxon under the trade designation "PolyPro 3445".
The production tool was embossed off of a nickel-plated

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master. The master tool was made by diamond cutting a
pattern of varying dimension grooves and indentations
according to the computer programs described in the
APPENDIX, and then nickel plated. The APPENDIX includes
5 the source code for four computer programs, which, in
general, comprises a first program entitled "VARI-
1.BAS", which generated and determined random left and
right angles for side surfaces of five sided pyramidal
shapes and also the material included angles for these
10 shapes; the second program entitled "VARI-STAT.BAS"
statistically tallied the number and values of the
left, right, and material included angles in x and y
coordinates in the array of shapes to assure
randomness; the third program entitled "TOPVIEW.BAS"
15 took the random angle file and calculated where the
valleys and peaks appear for the shapes having the
angles determined by the first program for a square
inch (6.5 cm²) and printed out a display on a computer
screen or printer of the topography of the array of
20 shapes; and the fourth program "MAKETAPE.BAS" took the
determined angles and generated a code to control the
number and type of grooves required to be cut by the
diamond turning machine to make a 22.5 inch (57 cm)
wide pattern of random shapes generated by the first
25 program.

In general, the production tool, as made from the
master tool made using the above-mentioned four
programs, contained an array of cavities that were
inverted five sided pyramids (inclusive of the mouth of
30 the cavity as a "base") that had a constant depth of
about 355 micrometers but varied in dimension between 8
and 45 degrees for adjacent cavities in terms of the
angle made by side faces with the intersection of a
plane extending normal to the plane of tool and the
35 material included angle or apex angle of each composite
was at least 25 degrees.

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The abrasive article was made by a method and
arrangement generally depicted in Figure 3. This
process was a continuous process that operated at about
15.25 meters/minute. The backing was a J weight rayon
5 backing that contained a dried latex/phenolic presize
coating to seal the backing. The abrasive slurry was
knife-coated onto a production tool with a 76
micrometer knife gap (3 mil) and about a 15 cm wide
coating area onto the production tool. The nip
10 pressure, such as exerted by roll 47 in Figure 3,
between the production tool and the backing was about
40 pounds. The energy source was one visible-light
lamp, which contained a V-bulb made by Fusion Systems,
Co., which operated at 600 Watts/inch (240 Watt/cm).
15 After curing the abrasive slurry, the resulting coated
abrasive was thermally cured for 12 hours at 240°F
(116°C) to final cure the phenolic presize of the
backing.

Test Procedure I
20   The coated abrasive article was converted into 7.6
cm by 335 cm endless belt and tested on a constant load
surface grinder. A pre-weighed, 4150 mild steel
workpiece approximately 2.5 cm by 5 cm by 18 cm was
mounted in a holder. The workpiece was positioned
25 vertically, with the 2.5 cm by 18 cm face facing an
approximately 36 cm diameter 65 Shore A durometer
serrated rubber contact wheel with one on one lands
over which was entrained the coated abrasive belt. The
workpiece was then reciprocated vertically through an
30 18 cm path at the rate of 20 cycles per minute, while a
spring loaded plunger urged the workpiece against the
belt with a load of 4.5 kg (10 lbs) as the belt was
driven at about 2050 meters per minute. After thirty
seconds elapsed grinding time, the workpiece holder
35 assembly was removed and re-weighed, the amount of
stock removed calculated by subtracting the abraded

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weight from the original weight, and a new, pre-weighed
workpiece and holder were mounted on the equipment.
Additionally, the surface finish (Ra) and, in some
cases, the Rtm, of the workpiece was also measured and
5   these procedures will be described below. The test
endpoint was when the amount of steel removed in the
thirty second interval was less than one third the
value of the steel removed in the first thirty seconds
of grinding or until the workpiece burned, i.e., became
10 discolored.

Test Procedure II

The same procedure as Test Procedure I was used
except that a 1018 mild steel workpiece was used.

Test Procedure III

15   A maple dowel rod that had a diameter of
approximately 3 cm was installed on a lathe. The dowel
rod was rotated at about 3800 rpm. A strip of abrasive
article (1 inch (2.64 cm) wide and 12 inches (30.5 cm)
long) was held against the dowel rod without any
20 oscillation for approximately 15 to 20 seconds. After
abrading, the dowel rod was stained with a cherry oil
stain commercially available from Watco.

Ra is a common measure of roughness used in the
abrasives industry. Ra is defined as the arithmetic
25 mean of the departures of the roughness profile from
the mean line. Ra was measured with a profilometer
probe, which was a diamond tipped stylus. In general,
the lower the Ra value was, the smoother or finer the
workpiece surface finish. The results were recorded in
30 micrometers. The profilometer used was a Perthen M4P.

Rtm is a common measure of roughness used in the
abrasive industry. Rtm is defined as the mean of five
individual roughness depths of five successive
measuring lengths, where an individual roughness depth
35 is the vertical distance between the highest and lowest
points in a measuring length. Rtm is measured the same

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as Ra. The results are recorded in micrometers. In
general, the lower the Rtm, the smoother the finish.

Examples

5 ### Examples 1, 1A and Comparative Examples A, AA

Abrasive articles representative of the invention
were compared with conventional coated abrasive
articles having uniformly shaped and dimensioned
abrasive composites. Example 1 was made according to
10 the "General Procedure for Making the Abrasive Article"
describe herein. Comparative Example A was a grade P320
3M 201E Three-M-ite Resin Bond cloth JE-VF coated
abrasive commercially available from 3M Company, St.
Paul, MN. These abrasive products were tested
15 according to Test Procedure I and the test results can
be found in Table 1. Also, additional Example 1A and
Comparative Example AA were performed wherein Example 1
and Comparative Example A were repeated, except that
Test Procedure II was used in lieu of Test Procedure I.
20 The results also are summarized in Table 1.

Table 1

Run	Ex. 1	C.Ex. A	Ex. 1A	C. Ex. AA
Init. Cut (grams)	12.2	15.3	13.3	11.8
Init. Ra (μm)	0.86	0.88	0.98	1.18
Init.Rtm (μm)			9.43	10.66
Total Cut (grams)	283.6	156.8	255.5	247.2
Final Ra(μm)	0.33	0.43	0.37	0.40
Final Rtm (μm)			3.11	3.92

25

30

35

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The above results show that the abrasive articles
of the present invention, as represented by Examples 1
and 1A, demonstrated higher cut and provided finer
finish than the comparison examples using exclusively
5   identically shaped abrasive composites.

Example 2 and Comparative Examples B through E

This set of examples compared the abrasive article
of the invention with abrasive articles that had only
one commonly shaped and dimensioned type of abrasive
10 composite present on the backing. All of these
examples were made according to "General Procedure for
Making the Abrasive Article," described above, except
for the following changes. The abrasive slurry
consisted of 20.3 parts TMPTA, 8.7 parts TATHEIC, 1
15 part PH2, 1 part ASF, 1 part SCA, and 69 parts of 40
micrometer WAO. Also, the production tool for
Comparative Examples B through E was an embossed
polypropylene thermoplastic continuous web that
contained five sided pyramidal type cavities (inclusive
20 of the mouth of the cavity as a "base"). The cavities
for Comparative Examples B through E were all identical
in dimensions and the cavities butted up against one
another. The height of the cavities for Comparative
Example B was about 178 micrometers, for Comparative
25 Example C was about 63.5 micrometers, for Comparative
Example D was about 711 micrometers and Comparative
Example E was about 356 micrometers.

Example 2 and Comparative Examples B through E
then were tested according to Test Procedure III above.
30 The stained maple dowel rod abraded with Comparative
Examples B through E showed evidence of grooves visible
by the naked eye. In contrast, the stained maple dowel
rod abraded with Example 2 representing the present
invention showed no evidence of grooves visible by the

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naked eye and produced a very fine finish on the wood
workpiece.

     Various modifications and alterations of this
invention will become apparent to those skilled in the
5 art without departing from the scope and spirit of this
invention, and it should be understood that this
invention is not to be unduly limited to the
illustrative embodiments set forth herein.

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Appendix

```
'****************************
'**Program : VARI-1.BAS        *
'****************************
5   ' VARI-1.BAS - Creates random left and right half
    angles
    '
    DECLARE SUB showangles ()
    DIM SHARED LEFTANG(3000) AS INTEGER
10  DIM SHARED RIGHTANG(3000) AS INTEGER
    '******* Begin Main Program *****
    PI = 3.141592654#
    RANDOMIZE TIMER
    CLS
15  INPUT "WHAT IS THE TOOL ANGLE  ", ToolAng
    INPUT "WHAT IS THE MINIMUM HALF ANGLE  ", MinHalfAng
    INPUT "WHAT IS THE MAXIMUM HALF ANGLE  ", MaxHalfAng
    INPUT "WHAT IS THE MINIMUM INCLUDED ANGLE OF THE
    MATERIAL  ", MinInclAng
20  ANG1 = 45
    'ANG1 is the previous grooves Right half angle
    'ANG1 & 2 are used to check the MinInclAng
    FOR I =  1 TO 2500 STEP 2
        '** Calculate Odd Numbered Groove Angles ****
25      FOR T = 1 TO INT(RND * 100 + 1): NEXT T
    'This is a random delay
        IF MinInclAng - ANG1 > MinHalfAng THEN
          min = MinInclAng - ANG1
        ELSE
30        min = MinHalfAng
        END IF
        LEFTANG(I) = INT(RND * (MaxHalfAng - min + 1)+
    min)
        IF ToolAng - LEFTANG(I) > MinHalfAng THEN
35        min = ToolAng - LEFTANG(I)
        ELSE
```

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```
              min = MinHalfAng
          END IF
          RIGHTANG(I) = INT(RND * (MaxHalfAng - (min) + 1) +
      (min))
5         ANG2 = RIGHTANG(I)
          '** End Calculate Odd Number Groove angles **
          '** Begin Calculating Even Numbered Groove angles
          **
      FOR T = 1 TO INT(RND * 100 + 1): NEXT T
10    'This is a random delay
      RIGHTANG(I + 1) = INT(RND * (MaxHalfAng - MinHalfAng +
      1) + MinHalfAng)
      IF ToolAng - RIGHTANG(I + 1) > MinHalfAng THEN
          min = ToolAng - RIGHTANG(I + 1)
15    ELSE
          min = MinHalfAng
      END IF
      IF MinInclAng - ANG2 > min THEN
          min = MinInclAng - ANG2
20    ELSE
          min = min
      END IF
      LEFTANG(I + 1) = INT(RND * (MaxHalfAng - (min) 1) +
      (min))
25    ANG1 = RIGHTANG(I + 1)
          '** End Calculating Even Numbered Groove Angles **

      NEXT I
      CALL showangles
30    OPEN "RANANG.TXT" FOR OUTPUT AS #3
      PRINT #3, "RANDOM ANGLE GENERATOR"
      PRINT #3, "LEFT ANG    RIGHT ANG"
      FOR I = 1 TO 2500
          PRINT #3, LEFTANG(I); RIGHTANG(I)
35    NEXT I
```

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```
   CLOSE 3

   '**************** End Main Program*************
   '
 5 SUB showangles 'This subroutine shows the first 30
   grooves

   CLS
   SCREEN 9
10 COLOR 3
   SLEEP 2
   PI   3.141592654#
       FOR I = 1 TO 30
          'LOCATE 1, 1: PRINT LEFTANG(I), RIGHTANG(I),
15 LEFTANG(I) + RIGHTANG(I)
          A = (TAN(LEFTANG(I) * PI / 180) * 200)
          LINE (200, 100)-(200 - A, 300), 3
          B = (TAN(RIGHTANG(I) * PI / 180) * 200)
          LINE (200, 100)-(200 + B, 300), 3
20        FOR T = 1 TO 200000: NEXT T
          LINE (200, 100)-(200 - A, 300), 0
          LINE (200, 100)-(200 + B, 300), 0
       NEXT I
   END SUB
25 _____

   _____


   '****************************
   '** Program : VARISTAT.BAS   *
30 ****************************

   DECLARE SUB SETGRAPH2 () 'Graph for Included Angles
   DECLARE SUB ANGLEGEN ()       'Main Subroutine
   DECLARE  SUB XGEN ()          'Subroutine for Tests
35 only
   DECLARE  SUB SETGRAPH () 'Graph for Half Angles
```

```
      DIM SHARED ANGLEFT(2501) AS INTEGER      'Array for left
      half angles Direction 1
      DIM SHARED ANGRIGHT(2501) AS INTEGER      'Array for
      right half angles Direction 1
  5   DIM SHARED ANGLEFT2(2501) AS INTEGER      'Array for left
      half angles Direction 2
      DIM SHARED ANGRIGHT2(2501) AS INTEGER     'Array for
      right half angles Direction 2
      DIM SHARED HALF(8 TO 45) AS INTEGER      'Array to tally
 10   number of angles between 8 and 45 Direction 1
      DIM SHARED HALF2(8 TO 45) AS INTEGER      'Array to tally
      number of angles between 8 and 45 Direction 2
      DIM SHARED ACCUM(O TO 100) AS INTEGER    'Array to tally
      number of included angles between 40 and 90 Dir
 15   DIM SHARED ACCUM2(O TO 100) AS INTEGER   'Array to tally
      number of included angles between 40 and 90 Dir


      CLS                    •
      CALL ANGLEGEN
 20   'CALL  XGEN   'This was for test purposes only
      SUB  ANGLEGEN
      CALL SETGRAPH
      OPEN "RANANG.TXT" FOR INPUT AS #3
      'Two different .TXT files would have been created,
 25   however here we use the same file
      OPEN "RANANG.TXT" FOR INPUT AS #4
      INPUT #3,  A$
      INPUT #3,  B$
      INPUT #4,  A$
 30   INPUT #4,  B$
      FOR I = 1 TO 2500
            INPUT #3, ANGLEFT(I)
            INPUT #3, ANGRIGHT(I)
            INPUT #4, ANGLEFT2(I)
 35         INPUT #4, ANGRIGHT2(I)
      NEXT  I
```

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```
        CLOSE 3, 4

        FOR I = 1 TO 2500
            HALF(ANGLEFT(I)) = HALF(ANGLEFT(I)) + 1
5           HALF2(ANGRIGHT(I)) = HALF2(ANGRIGHT(I)) + 1
        NEXT I


        LOCATE 2, 10: COLOR 11
        PRINT  "First Direction Total Left Half Angle"
10      LOCATE 3, 10: COLOR  12
        PRINT  "First Direction Total Right Half Angle"


        FOR I = 8 TO 45
            LINE (I, 0)-(I, HALF(I)), 11
15          LINE (I + .5, 0)-(I + .5, HALF2(I)), 12
            HALF(I) = 0
            HALF2(I) = 0
        NEXT I
        SLEEP
20
        CALL SETGRAPH
        LOCATE 2, 10: COLOR 11
        PRINT "Second Direction Total Left Half Angle"
        LOCATE 3, 10: COLOR 12
25      PRINT "Second Direction Total Right Half Angle"


        FOR I = 1 TO 2500
            HALF(ANGLEFT2(I)) = HALF(ANGLEFT2(I)) + 1
            HALF2(ANGRIGHT2(I)) = HALF2(ANGRIGHT2(I)) + 1
30      NEXT I


        FOR I = 8 TO 45
            LINE (I, 0)-(I, HALF(I)), 11
            HALF(I) = 0
35          LINE (I + .5, 0)-(I + .5, HALF2(I)), 12
            HALF2(I) = 0
```

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```
    NEXT I
    SLEEP

    CALL SETGRAPH2
 5  LOCATE 2, 10: COLOR 11
    PRINT "First Direction Total Included Angles (Left +
    Right Half Angle)"
    LOCATE 3, 10: COLOR 12
    PRINT "Second Direction Total Included Angles (Left +
10  Right Half Angle)"

    FOR I = 1 TO 2500
        ACCUM(ANGLEFT(I) + ANGRIGHT(I)) = ACCUM(ANGLEFT(I) +
    ANGRIGHT(I)) + 1
15      ACCUM2(ANGLEFT2(I) + ANGRIGHT2(I)) =
    ACCUM2(ANGLEFT2(I) + ANGRIGHT2(I)) + 1
    NEXT I
    FOR I = 40 TO 90
        LINE (I, 0)-(I, ACCUM(I)), 11
20      ACCUM(I) = 0
        LINE (I + .5, 0)-(I + .5, ACCUM2(I)), 12
        ACCUM2(I) = 0
    NEXT I
    SLEEP
25  END SUB

    SUB SETGRAPH

    SCREEN 9
30  WINDOW (4, -30)-(50, 200)
    CLS

    LINE (6, 0)-(6, 200), 3
    LINE (6, 0)-(50, 0), 3
35  LINE (6, 195)-(50, 195), 3
    LINE (6, 105)-(50, 105), 3
```

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```
      LINE (6, 50)-(50, 50), 3
      LINE (6, 150)-(50, 150), 3
      LOCATE 23, 7: PRINT "8"
      LOCATE 23, 72: PRINT "45"
   5  LOCATE 23, 40: PRINT "27"
      LOCATE 22, 3: PRINT "1"
      LOCATE 1, 1: PRINT "200"
      LOCATE 11, 1: PRINT "100",
      END SUB
  10
      SUB SETGRAPH2
      SCREEN 9
      WINDOW (37, -30)-(95, 200)
      CLS
  15
      LINE (39, 0)-(39, 200), 3
      LINE (39, 0)-(95, 0), 3
      LINE (39, 198)-(95, 198), 3
      LINE (39, 102)-(95, 102), 3
  20  LINE (39, 50)-(95, 50), 3
      LINE (39, 150)-(95, 150), 3
      LOCATE 23, 4: PRINT "40"
      LOCATE 23, 73: PRINT "90"
      LOCATE 23, 39: PRINT  "65"
  25  LOCATE 22, 3: PRINT "1"
      LOCATE 1, 1: PRINT "200"
      LOCATE 11, 1: PRINT "100"
      END SUB


  30  SUB XGEN     'This subroutine was for test purposes only


      CALL SETGRAPH
      OPEN "RANANG.TXT" FOR INPUT AS #3
      INPUT #3, A$
  35  INPUT #3, B$
      FOR I = 1 TO 2500
```

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```
      INPUT #3, ANGLEFT(I)
      INPUT #3, ANGRIGHT(I)
   NEXT I
   FOR I = 1 TO 2500
5      HALF(ANGLEFT(I)) = HALF(ANGLEFT(I)) + 1
   NEXT I


   FOR I = 8 TO 45
      LINE (I, 0)-(I, HALF(I)), 11
10     HALF(I) = 0
   NEXT I
   SLEEP


   CALL SETGRAPH
15 FOR I = 1 TO 2500
      HALF(ANGRIGHT(I)) = HALF(ANGRIGHT(I)) + 1
   NEXT I
   FOR I = 8 TO 45
      LINE (I, 0)-(I, HALF(I)), 11
20     HALF(I) = 0
   NEXT I
   SLEEP
   CALL SETGRAPH2
   FOR I = 1 TO 2500
25     ACCUM(ANGLEFT(I) + ANGRIGHT(I)) = ACCUM(ANGLEFT(I) +
   ANGRIGHT(I)) + 1
   NEXT I
   FOR I = 40 TO 90
      LINE (I, 0)-(I, ACCUM(I)), 11
30     ACCUM(I) = 0
   NEXT I
   SLEEP
   END SUB
```

35 _____

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```
*****************************
'** Program : TOPVIEW.BAS    *
*****************************
'* In general it takes the random angle data file,
calculates where the valleys and peaks are, draws black
straight lines for the valleys, then connects the peaks
across the diagonal.  Then it displays the output on
the screen or an HP 7475 plotter.  *
*****************************
10  DECLARE SUB PLOTPEAKS ()
    DECLARE SUB PLOTDOTS ()
    DECLARE SUB LINES ()
    DECLARE SUB DIAGONAL ()
    DIM SHARED ML(2500) AS INTEGER
15  DIM SHARED MR(2500) AS INTEGER
    DIM SHARED NL(2500) AS INTEGER
    DIM SHARED NR(2500) AS INTEGER

    DIM SHARED M(5000) AS DOUBLE
20  DIM SHARED N(5000) AS DOUBLE
    COMMON SHARED PI, X, GROOVES
    PI = 3.141592654#

    GROOVES = 1000
25  OPEN "RANANG.TXT" FOR INPUT AS #2
    OPEN "RANANG.TXT" FOR INPUT AS #3
    INPUT "ENTER IN THE SQUARE SIZE YOU WOULD LIKE (.2 ->
    1.5 INCHES)  ", X

30  INPUT #2, A$
    INPUT #2, B$
    FOR I = 1 TO GROOVES
      INPUT #2, ML(I)
      INPUT #2, MR(I)
35  NEXT I
    CLOSE 2
```

```
     INPUT #3, A$
     INPUT #3, B$
     FOR I = 1 TO GROOVES
          INPUT #3, NL(I)
5         INPUT #3, NR(I)
     NEXT I
     CLOSE 3


     FOR I = 1 TO GROOVES
10    M(I * 2 - 1) = M((I - 1) * 2) + TAN(ML(I) * PI / 180)
     * .014
     M(I * 2) = M(I * 2 - 1) + TAN(MR(I) * PI / 180) *
     .014
     N(I * 2 - 1) = N((I - 1) * 2) + TAN(NL(I) * PI / 180)
15   * .014
     N(I * 2) = N(I * 2 - 1) + TAN(NR(I) * PI / 180) *
     .014
     NEXT I


20   LOCATE 15, 15
     INPUT "Would you like to see the data on the (S)creen
     or (P)lotter", ans$
     ans$ = UCASE$(ans$)


25   IF ans$ = "S"  THEN
          SCREEN 9
          COLOR 0
          WINDOW SCREEN (-(X / 10), -(X / 10))-(X, (X + X /
     10) * (.75 - .75 * .138))
30        PAINT (X / 2, X / 2), 15
          CALL LINES
          SLEEP
          CLS
          PAINT (X / 2, X / 2), 15
35
          CALL DIAGONAL
```

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```
      END IF
      IF ans$ = "P" THEN
          CALL PLOTDOTS
          CALL PLOTPEAKS
5
          SLEEP
      END IF

      SUB DIAGONAL
10    FOR I = 1 TO GROOVES * 2 STEP 2
          'LINE (M(I), N(1))-(M(I), 10)
          'LINE (M(1), N(I))-(10, N(I))
      NEXT I


15    FOR I = 1 TO GROOVES * 2 - 2 STEP 2
          LINE (M(I), -.014)-(M(I + 1), 0)
          LINE (M(I + 1), 0)-(M(I + 2), -.014)
      NEXT I


20    LINE (M(1), -.014)-(M(1), -.02)
      LINE -(M(GROOVES * 2 - 2), -.02)
      LINE -(M(GROOVES * 2 - 2), -.014)
      FOR I = 1 TO GROOVES * 2 - 2 STEP 2
          LINE (-.014, N(I))-(0, N(I + 1))
25        LINE (0, N(I + 1))-(-.014, N(I + 2))
      NEXT I
      LINE (-.014, N(1))-(-.02, N(1))
      LINE -(-.02, N(GROOVES * 2 - 2))
      LINE -(-.014, N(GROOVES * 2 - 2))
30
      FOR NN = 2 TO GROOVES * 2 - 2 STEP 2
        FOR MM = 2 TO GROOVES * 2 - 2 STEP 2
            'LINE (M(MM), N(NN))-(M(MM + 1), N(NN + 1)), 2
            'LINE (M(MM), N(NN))-(M(MM + 1), N(NN - 1)), 4
35          'LINE (M(MM), N(NN))-(M(MM - 1), N(NN + 1)), 4
            'LINE (M(MM), N(NN))-(M(MM - 1), N(NN - 1)), 2
```

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```
          LINE (M(MM), N(NN))-(M(MM + 2), N(NN + 2)), 2
          'LINE (M(MM), N(NN))-(M(MM + 2), N(NN - 2)), 4
          PSET (M(MM), N(NN)), 4
          IF M(MM - 1) > X THEN GOTO STOPMM
5         IF N(NN - 1) > (X + X / 10) * (.75 - .75 * .138)
   THEN GOTO STOPNN
     NEXT MM
   STOPMM:
   NEXT NN
10 'PAINT (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
   / 2), 11
   'CIRCLE (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
   / 2), .001, 11
   STOPNN:
15 BEEP
   END SUB


   SUB LINES
   FOR I = 1 TO 200 STEP 2
20    LINE (M(I), N(1))-(M(I), 10)
      LINE (M(1), N(I))-(10, N(I))
   NEXT I


   FOR I = 1 TO 198 STEP 2
25    LINE (M(I), -.014)-(M(I + 1), 0)
      LINE (M(I + 1), 0)-(M(I + 2), -.014)
   NEXT I
   LINE (M(1), -.014)-(M(1), -.02)
   LINE -(M(198), -.02)
30 LINE -(M(198), -.014)
   FOR I = 1 TO 198 STEP 2
      LINE (-.014, N(I))-(0, N(I + 1))
      LINE (0, N(I + 1))-(-.014, N(I + 2))
   NEXT I
35 LINE (-.014, N(1))-(-.02, N(1))
   LINE -(-.02, N(198))
```

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```
    LINE -(-.014, N(198))

    FOR NN = 2 TO 198 STEP 2
      FOR MM = 2 TO 198 STEP 2
5         LINE (M(MM), N(NN))-(M(MM + 1), N(NN + 1)), 2
          LINE (M(MM), N(NN))-(M(MM + 1), N(NN - 1)), 4
          LINE (M(MM), N(NN))-(M(MM - 1), N(NN + 1)), 4
          LINE (M(MM), N(NN))-(M(MM - 1), N(NN - 1)), 2
          IF M(MM - 1) > X THEN GOTO 300
10        IF N(NN - 1) > (X + X / 10) * (.75 - .75 * .138)
    THEN GOTO 200
      NEXT MM
    300
    NEXT NN
15  'PAINT (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
    / 2), 11
    'CIRCLE (M(5) + (M(6) - M(5)) / 2, N(6) - (N(6) - N(5))
    / 2), .001, 11
    200
20  BEEP
    END SUB


    SUB PLOTDOTS
    'WINDOW SCREEN (-(X / 10), -(X / 10))-(X, (X + X / 10)
25  * (.75 - .75 * .138))

    OPEN "COM1:9600,S,7,1,RS,CS65535,DS,CD" FOR RANDOM AS
    #4
    'PRINT #4, USING "IP;
30  SC##.#####,##.#####,##.#####,##.#####;"; (-(X / 10));
    (X); (-(X / 10)); ((X + X / 10
    'PRINT #4, USING "IP250,596,7470,7796;
    SC##.#####,##.#####,##.#####,##.#####;"; 0; 4; 0; 3
    PRINT #4, "IN;IP250,596,7443,7796; SC0,1,0,1;"
35  PRINT #4, "VS30;"
    PRINT #4, "SP1;"
```

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```
     FOR I = 1 TO GROOVES * 2 STEP 2
        'LINE (M(I), N(1))-(M(I), 10)
        'LINE (M(1), N(I))-(10, N(I))
     NEXT I
  5
     PRINT #4, USING "PA ##.####, -.014;"; M(1)
     PRINT #4, "PD;"

     FOR I = 2 TO GROOVES * 2 - 2 STEP 2
 10     'LINE (M(I), -.014)-(M(I + 1), 0)
        PRINT #4, USING "PA ##.####, 0"; M(I)
        'LINE (M(I + 1), 0)-(M(I + 2), -.014)
        PRINT #4, USING "PA ##.####,-.014"; M(I + 1)
        P = I + 1
 15     IF M(I + 1) > X THEN GOTO 600
     NEXT I
     600
     'LINE (M(1), -.014)-(M(1), -.02)
     PRINT #4, USING "PA ##.####, -.03;"; M(P)
 20  'LINE -(M(P), -.02)
     PRINT #4, USING "PA ##.####, -.03;"; M(1)
     'LINE -(M(P), -.014)
     PRINT #4, USING "PA ##.####,-.014;PU;"; M(1)
     PRINT #4, USING "PA -.014,##.####;PD;"; N(1)
 25  FOR I = 2 TO GROOVES * 2 - 2 STEP 2
        'LINE (-.014, N(I))-(0, N(I + 1))
        PRINT #4, USING "PA 0,##.####;"; N(I)
        'LINE (0, N(I + 1))-(-.014, N(I + 2))
        PRINT #4, USING "PA -.014,##.####;"; N(I + 1)
 30     Q = I+ 1
        IF N(I + 1) > X THEN GOTO 700
     NEXT I
     700
     'LINE (-.014, N(1))-(-.02, N(1))
 35. PRINT #4, USING "PA -.03,##.####;"; N(Q)
     'LINE -(-.02, N(Q))
```

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```
      PRINT #4, USING "PA -.03,##.####;"; N(1)
      'LINE -(-.014, N(Q))
      PRINT #4, USING "PA -.014,##.####;PU;"; N(1)
      PRINT #4, "SP4;"
 5
      PRINT #4, USING "PA ##.####,##.####;PD;"; M(2); N(2)
      A = 2
      FOR B = 2 TO P STEP 2
        FOR COUNT = 0 TO Q - 1 STEP 2
10          'LINE (M(MM), N(NN))-(M(MM + 2), N(NN + 2)), 2
            PRINT #4, USING "PD;PA ##.####,##.####;"; M(B +
      COUNT) N (A + COUNT)
            IF M(B + COUNT - 1) > X THEN GOTO 400
            IF N(A + COUNT - 1) > X THEN GOTO 400
15      NEXT COUNT
      400
      PRINT #4, "PU;"
      PRINT #4, USING "PA ##.####,##.####;"; M (B + 2); N
      (A)
20 NEXT B

      PRINT #4, USING "PA ##.####,##.####;PD;"; M(2); N(4)
      B = 2
      FOR A = 4 TO Q STEP 2
25    FOR COUNT = 0 TO P - 1 STEP 2
            'LINE (M(MM), N(NN))-(M(MM + 2), N(NN + 2)), 2
            PRINT #4, USING "PD;PA ##.####,##.####;"; M(B +
      COUNT); N(A + COUNT)
            IF M(B + COUNT - 1) > X THEN GOTO 401
30          IF N(A + COUNT - 1) > X THEN GOTO 401
        NEXT COUNT
      401
      PRINT #4, "PU;"
      PRINT #4, USING "PA ##.####,##.####;"; M(B); N(A + 2)
35 NEXT A
```

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```
        'PRINT #4,
        "PA.25,.25;PD;PA.75,.25;PA.75,.75;PA.25,.75;PA.25,.25;"
        500
        BEEP
     5  CLOSE 4
        END SUB
        SUB PLOTPEAKS

        OPEN "COM1:9600,S,7,1,RS,CS65535,DS,CD" FOR RANDOM AS
    10  #4
        PRINT #4, "IN;IP250,596,7443,7796; SCO,1,0,1;"

        PRINT #4, "VS50;"

    15  PRINT #4, "SP1;"

        PRINT #4, USING "PA ##.#####, -.014;"; M(1)
        PRINT #4, "PD;"

    20  FOR I = 2 TO GROOVES * 2 - 2 STEP 2
           PRINT #4, USING "PA ##.#####, O"; M(I)
           PRINT #4, USING "PA ##.#####,-.014"; M(I + 1)
           P = I + 1
           IF M(I + 1) > X THEN GOTO 1600
    25  NEXT I
        1600

        PRINT #4, USING "PA ##.#####, -.03;"; M(P)
        PRINT #4, USING "PA ##.#####, -.03;"; M(1)
    30  PRINT #4, USING "PA ##.#####,-.014;PU;"; M(1)

        PRINT #4, USING "PA -.014,##.#####;PD;"; N(1)
        FOR I = 2 TO GROOVES * 2 - 2 STEP 2
           PRINT #4, USING "PA O,##.#####;"; N(I)
    35     PRINT #4, USING "PA -.014,##.#####;"; N(I + 1)
           Q = I + 1
```

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```
        IF N(I + 1) > X THEN GOTO 1700
    NEXT I
    1700

 5  PRINT #4, USING "PA -.03,##.#####;"; N(Q)
    PRINT #4, USING "PA -.03,##.#####;"; N(1)
    PRINT #4, USING "PA -.014,##.#####;PU;"; N(1)

    FOR I = 1 TO P STEP 4
10    PRINT #4, USING "PA
    ##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(I);
    N(1); M(I); N(Q)
        PRINT #4, USING "PA
    ##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(I +
15  2); N(Q); M(I + 2); N(1)
    NEXT I

    FOR I = 1 TO Q STEP 4
        PRINT #4, USING "PA
20  ##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(1);
    N(I); M(P); N(I)
        PRINT #4, USING "PA
    ##.#####,##.#####;PD;PA##.#####,##.#####;PU;"; M(P);
    N(I + 2); M(1); N(I + 2)
25  NEXT I

    PRINT #4, "SP4;VS20;"

    PRINT #4, USING "PA ##.#####,##.#####;"; M(1); N(1)
30  A = 1
    FOR B = 1 TO P STEP 2
        FOR COUNT = 0 TO Q - 1 STEP 1
            PRINT #4, USING "PD;PA ##.#####,##.#####;"; M(B +
    COUNT); N(A + COUNT)
35          IF M(B + COUNT - 1) > X THEN GOTO 1400
            IF N(A + COUNT - 1) > X THEN GOTO 1400
```

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```
      NEXT COUNT
      1400
      PRINT #4, "PU;"
      PRINT #4, USING "PA ##.####,##.####;"; M(B + 2); N(A)
 5    NEXT B


      PRINT #4, "SP3;"
      PRINT #4, USING "PA ##.####,##.####;"; M(P); N(1)
      A = 1
10    FOR B = P TO 1 STEP -2
        FOR COUNT = 0 TO Q - 1 STEP 1
          PRINT #4, USING "PD;PA ##.####,##.####;"; M(B -
      COUNT); N(A + COUNT)
          IF B - COUNT 1 = 0 THEN GOTO 2500
15        IF A + COUNT = Q THEN GOTO 2500
        NEXT COUNT
      2500
      PRINT #4, "PU;"
      IF B - 2 <= 0 THEN GOTO 2000
20    PRINT #4, USING "PA ##.####,##.####;"; M(B - 2); N(A)
      NEXT B
      2000


      PRINT #4, "SP4;"
25    PRINT #4, USING "PA ##.####,##.####;"; M(1); N(3)
      B = 1
      FOR A = 3 TO Q STEP 2
        FOR COUNT = 0 TO P - 1 STEP 1
          PRINT #4, USING "PD;PA ##.####,##.####;"; M(B +
30    COUNT); N(A + COUNT)
          IF M(B + COUNT - 1) > X THEN GOTO 1401
          IF N(A + COUNT - 1) > X THEN GOTO 1401
        NEXT COUNT
      1401
35    PRINT #4, "PU;"
      PRINT #4, USING "PA ##.####,##.####;"; M(B); N(A + 2)
```

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SUBSTITUTE SHEET (RULE 26)

```
    NEXT A

    PRINT #4, "SP3;"
    PRINT #4, USING "PA ##.####,##.####;"; M(P); N(3)
 5  B = P
    FOR A = 3 TO Q STEP 2
      FOR COUNT = 0 TO Q - 1 STEP 1
          PRINT #4, USING "PD;PA ##.####,##.####;"; M(B -
    COUNT); N(A + COUNT)
10        IF B - COUNT - 1 = 0 THEN GOTO 2400
          IF A + COUNT = Q THEN GOTO 2400
      NEXT COUNT
    2400
    PRINT #4, "PU;"
15  PRINT #4, USING "PA ##.####,##.####;"; M(B); N(A + 2)
    NEXT A

    BEEP
    CLOSE 4
20  END SUB
```

_____

_____

```
    '****************************
25  '** Program : MAKETAPE.BAS    *
    '****************************

    'MAKETAPE.BAS
    '         1)   Ask for the real tool angle
30  '         2)   Read in all Left and Right angles
    '         3)   Figure out how many grooves it will take to
                   make a 22.5 inch wide pattern
    '         4)   Write the Code
    '
35  '
    '
```

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```
   DECLARE SUB STOPFANUK ()   ' Code to shut down DTM
   DECLARE SUB STARTFANUK ()  ' Code to start up DTM
   DECLARE SUB XthenLEFT (A!)  ' Code generation for: X
   move then Left angle plunge
 5 DECLARE SUB ROTATEthenRIGHT (A!)  ' Code generation for:
   Rotate C then Right angle plunge
   DECLARE SUB XthenRIGHT (A!)   ' Code generation for: X
   move then Right angle plunge
   DECLARE SUB ROTATEthenLEFT (A!) ' Code generation for:
10 Rotate C then Left angle plunge

   '* LEFT() - array to store the left angle information
   '* RIGHT() - array to store the right angle information
   '* XMOVE() - array to store the X distance between
15 grooves

   DIM SHARED LEFT(2500) AS INTEGER, RIGHT(2500) AS
   INTEGER
   DIM SHARED XMOVE(2500) AS DOUBLE
20 COMMON SHARED TOOLANG AS DOUBLE, CABS AS DOUBLE, XPOS
   AS DOUBLE

   '******** BEGIN MAIN PROGRAM *********
   PI = 3.141592654#
25
   CLS
   LOCATE 5, 5
   INPUT "WHAT IS THE REAL TOOL ANGLE  ", TOOLANG
   INPUT "WHAT IS THE PEAK HEIGHT  ", Height
30
   OPEN "RANANG.TXT" FOR INPUT AS #3       'Opens data file
   of angles
   INPUT #3, A$
   INPUT #3, B$
35
```

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```
       FOR I = 1 TO 2500   'Reads all Left and Right angles
       from data file
          INPUT #3, LEFT(I)
          INPUT #3, RIGHT(I)
   5   NEXT I
       CLOSE 3


       XMOVE(1) = TAN(LEFT(1) * PI / 180) * Height  ' This
  10   formula calculates the  horizontal movement for the
       first groove

       XPOS = XPOS + XMOVE(1)
       FOR I = 2 TO 2500
  15      XMOVE(I) = TAN(RIGHT(I - 1) * PI / 180) *
       Height + TAN(LEFT(I) * PI / 180) * Height

       ' This formula calculates the horizontal movement
          XPOS = XPOS + XMOVE(I)
  20      P = I
       ' P is the number of grooves
          IF XPOS > 22.5 THEN GOTO 100
       ' Checks to make sure our pattern width is < 22.5
       NEXT I
  25   100


       LOCATE 10, 10: PRINT USING "GROOVES = ####
       : PATTERN WIDTH = ##.####"; P; XPOS
       XPOS = 0
  30   OPEN "FANUK.TXT" FOR OUTPUT AS #3
       PRINT "WRITING TO FILE"


       CALL STARTFANUK    '* This Block of code Generates the
       CNC file to run the FANUK controller
  35   FOR I = 1 TO P STEP 2                          '*
          CALL XthenLEFT(I)                           '*
```

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SUBSTITUTE SHEET (RULE 26)

```
          CALL ROTATEthenRIGHT(I)                    '*
          CALL XthenRIGHT(I + 1)                      '*
          CALL ROTATEthenLEFT(I + 1)                  '*
       NEXT I                                         '*
  5    CALL STOPFANUK                                 '*
       PRINT "DONE"

       CLOSE  3
       '********** END MAIN PROGRAM **************
 10

       '*****The information below describes the two
       subroutines of the CNC code ******

       'THE SUBROUTINES 0171 & 0172 ARE AS FOLLOWS
 15
       '0171;
       'G91 G01 Y 0.00200 F 1.0;
       'G91 G01 Y 0.01587 F 0.03;
       'G91 G01 Y 0.00013 F 0.005;
 20    'G04P245;
       'G91 G01  -0.013 F 1.0;
       'M99;
       ';


 25    '0172;
       'G91 G01 Y 0.01287 F 0.03;
       'G91 G01 Y 0.00013 F 0.005;
       'G04P245;
       'G91 G01 Y -0.018 F 1.0;
 30    'M99;
       ';


       SUB ROTATEthenLEFT (A)


 35    CABS = -1 * (LEFT(A) + 90) + TOOLANG
       PRINT #3, USING "G01 G90 C ##.##### F 300.0;"; CABS
```

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SUBSTITUTE SHEET (RULE 26)

```
        PRINT #3, "M98 P172 L1;"

        END SUB

  5   SUB ROTATEthenRIGHT,(A)

        CABS = -1 * (90 - RIGHT(A))
        PRINT #3, USING "G01 G90 C ##.##### F 300.0;"; CABS
        PRINT #3, "M98 P172 L1;"
 10
        END SUB

        SUB STARTFANUK

 15   PRINT #3, ";"
        PRINT #3, "G94 G20 G61;"

        END SUB            •

 20   SUB STOPFANUK

        PRINT #3, "M54;"
        PRINT #3, "M50;"
        PRINT #3, "M58;"
 25   PRINT #3, "M59;"
        PRINT #3, "M51;"
        PRINT #3, "M02;"
        PRINT #3, "MOO;"
        PRINT #3, ";"
 30
        END SUB

        SUB XthenLEFT (A)

 35   PRINT #3, USING "GOO G91 X  ##.##### F 1.0;"; XMOVE(A)
        XPOS = XPOS + XMOVE(A)
```

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```
      CABS = -1 * (LEFT(A) + 90) + TOOLANG
      PRINT #3, USING "G01 G90 C ####.###### F 300.0;"; CABS
      PRINT #3, "M98 P171 L1;"

 5    END SUB


      SUB XthenRIGHT (A)
      PRINT #3, USING "GOO G91 X ##.###### F 1.0;"; XMOVE(A)
      XPOS = XPOS + XMOVE(A)
10    CABS = -1 * (90 - RIGHT(A))
      PRINT #3, USING "G01 G90 C ####.###### F 300.0;"; CABS
      PRINT #3, "M98 P171 L1;"

      END SUB
15    _____

      _____
```

CLAIMS:

    1. An abrasive article (10) comprising a sheet-
like structure having a major surface (16) having
5 deployed in fixed position thereon a plurality of
three-dimensional abrasive composites (12), each of
said composites (12) comprising abrasive particles (13)
dispersed in a binder (14) and having a substantially
precise shape defined by a substantially distinct and
10 discernible boundary (15) which includes substantially
specific dimensions, wherein said precise shapes are
not all identical.

    2. The abrasive article of claim 1, wherein
15 substantially all of said abrasive composites exist as
pairs, each pair including two unmatched abrasive
composites, one abrasive composite having a
nonidentical shape to an adjacent abrasive composite.

20   3. The abrasive article of claim 1, wherein said
abrasive composites include a first abrasive composite
having a first precise shape having specific first
dimensions and a second abrasive composite having a
second precise shape and second specific dimensions
25 wherein said first and the second specific dimensions
are not the same.

    4. The abrasive article of claim 3, wherein said
first and second abrasive composites each has a
30 boundary defined by at least four planar surfaces
wherein adjacent planar surfaces meet to define an edge
of a certain length, wherein at least one edge of said
first composite has a length which is different from
the length of all edges of the second composite.
35

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5.   The abrasive article of claim 4, wherein the
length of said at least one edge of said first
composite has a length which varies with respect to the
length of any edge of said second composite in a ratio
5   between 10:1 to 1:10, not inclusive of 1:1.

6.   The abrasive article of claim 3, wherein said
first and second abrasive composites have a first and
second geometrical shape, respectively, which are
10   nonidentical.

7.   The abrasive article of claim 6, wherein said
first and second geometrical shapes are selected from
the group of geometrical shapes consisting of cubic,
15   prismatic, conical, truncated conical, cylindrical,
pyramidal, and truncated pyramidal.

8.   The abrasive article of claim 3, wherein
each of said abrasive composites has a boundary defined
20   by at least four planar surfaces wherein adjacent
planar surfaces meet an edge to define an angle of
intersection therebetween, wherein at least one angle
of intersection of said first abrasive composite is
different from all of the angles of intersection of
25   said second composite.

9.   The abrasive article of claim 8, wherein no
angle of intersection of adjacent planar surfaces in
said first abrasive composite is equal to 0° or 90°.
30

10.   The abrasive article of claim 8, wherein
substantially all said abrasive composites have a
pyramidal shape.

35   11.   The abrasive article of claim 1, wherein said
surface has a machine direction and opposite side

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edges, each side edge being parallel to the machine
direction axis and each side edge being respectively
within a first and second imaginary plane each of which
is perpendicular to said surface, a plurality of
5 parallel elongate abrasive ridges deployed in fixed
position on said surface, each ridge having a
longitudinal axis located at its transverse center and
extending along an imaginary line which intersects said
first and second planes at an angle which is neither 0°
10 nor 90°, and wherein each said abrasive ridge comprises
a plurality of said three-dimensional abrasive
composites which are intermittently spaced along said
longitudinal axis.

15   12.   The abrasive article of claim 11, wherein
said plurality of parallel elongate abrasive ridges are
deployed in first and second groups wherein said first
and second groups are located at nonoverlapping
locations in said machine direction or in a direction
20 perpendicular to said machine direction of said major
surface, wherein said longitudinal axis of at least one
abrasive ridge within said first group extends along an
imaginary line that intersects with an imaginary line
extending from at least one longitudinal axis of an
25 abrasive ridge in said second group.

          13.   The abrasive article of claim 11, wherein
each abrasive ridge has a distal end spaced from said
surface and each distal end extends to a third
30 imaginary plane which is spaced from and parallel to
said surface.

          14.   The abrasive article of claim 1, wherein each
said abrasive composite has a distal end which is
35 spaced from said surface a distance of about 50
micrometers to about 1020 micrometers.

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15.   The abrasive article of claim 1, wherein said abrasive composites are fixed on said major surface in a density of about 100 to about 10,000 abrasive composites/cm^2.

5

16.   The abrasive article of claim 1, wherein said surface has a surface area, and substantially all said surface area is covered by said abrasive composites.

10   17.   A method for manufacturing an abrasive article according to claim 1, comprising the steps of:

(a) preparing an abrasive slurry wherein the abrasive slurry comprises a plurality of abrasive particles dispersed in a binder precursor;

15   (b) providing a backing (41) having a front surface and a back surface; and a production tool (46) provided with a plurality of cavities in at least one major surface thereof, each cavity having a precise shape defined by a distinct and discernible boundary

20 which includes specific dimensions, wherein said precise cavity shapes are not all identical;

(c) providing a means (44) to apply said abrasive slurry into a plurality of said cavities of said production tool (46);

25   (d) contacting said front surface of said backing with said production tool such that the abrasive slurry wets said front surface;

(e) solidifying the binder precursor to form a binder, whereupon solidification the abrasive slurry is

30 converted into a plurality of abrasive composites; and

(f) separating said production tool from said backing after said solidifying to provide a plurality of abrasive composites as attached to said backing each having a precise shape defined by a distinct and

35 discernable boundary which include specific dimensions,

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wherein said precise abrasive composite shapes are not all identical.

18.   A method of refining a workpiece with the
5   abrasive article according to claim 1, comprising the steps of:
       (a) bringing into frictional contact a workpiece surface and said abrasive article; and
       (b) moving at least one of said abrasive
10 article or said workpiece surface relative to the other such that the surface finish of said workpiece surface is reduced.

19.   A production tool for manufacture of the
15 abrasive composites according to claim 1, comprising a sheet-like structure having a plurality of cavities formed on a major surface thereof, each cavity having a precise shape defined by a distinct and discernible boundary which includes specific dimensions, wherein
20 said precise cavity shapes are not all identical.

20.   A method for making a master that is used to form a production tool according to claim 19, said master having a major surface extending within a first
25 imaginary plane, comprising the steps of:
       (1) determining angles corresponding to facing right and left planar surfaces of adjacent three-dimensional shapes and wherein each of said angles has a value as measured between its planar surface and a
30 plane which extends in a normal direction to said master surface and contains an edge of said planar surface in contact with said surface, by the following substeps:
       (i) selecting an angle value between, but not
35 including, 0° and 90° to establish a first right half angle of a first right planar surface of a first right-

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side three-dimensional shape with a random number
generating means capable of randomly selecting an angle
value between, but not including, 0° and 90°;

     (ii) selecting an angle value between, but not
5 including, 0° and 90° with said random number·
generating means to establish a first left half angle
for a first left planar surface of a first left-side
three-dimensional shape facing said first right planar
surface of said first right-side three-dimensional
10 shape;

     (iii) proceeding along a first direction
extending linearly within said first imaginary plane to
a second left planar surface of a second left-side
three-dimensional shape located adjacent said first
15 left-side three-dimensional shape and using said random
number generating means to select a value between, but
not including, 0° and 90° to establish a second left
planar angle for said second left planar surface;

     (iv) using said random number generating means
20 to select a value between, but not including, 0° and
90° for a second right planar surface of a second
right-side three-dimensional shape facing said second
left planar surface;

     (v) proceeding along said first direction to a
25 third right-side three-dimensional shape located
adjacent said second right-side three-dimensional
shape;

     (vi) repeating said substeps (i), (ii), (iii),
(iv), and (v), in that sequence, at least once;
30   (2) repeating step (1) except that the angles are
determined for left and right planar surfaces of
adjacent three-dimensional shapes deployed in two
adjacent rows in a second direction extending linearly
within said first imaginary plane, wherein said first
35 and second directions intersect;

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(3) using means to determine, for a given width of said surface of said master, locations of grooves required to be cut by a cutting means to form a series of intersecting grooves defining a plurality of precise
5 three-dimensional shapes having said angles calculated by steps (1) and (2); and

(4) providing a cutting means to cut grooves in said surface of said master in correspondence to said angles calculated by steps (1) and (2) and said groove
10 locations determined by step (3) to form a series of intersecting grooves which define a plurality of precise three-dimensional shapes upraised from said surface, each of said precise shapes being defined by a distinct and discernible boundary including specific
15 dimensions, wherein not all said three-dimensional shapes are identical; and, optionally,

(5) applying a molten solidifiable polymeric resin on said surface of said master in a manner effective to flow into and conform to said three-dimensional shapes;
20   (6) solidifying said polymeric resin into a sheet-form; and

(7) removing said sheet-form polymeric resin from said surface of said master to form said production tool.
25

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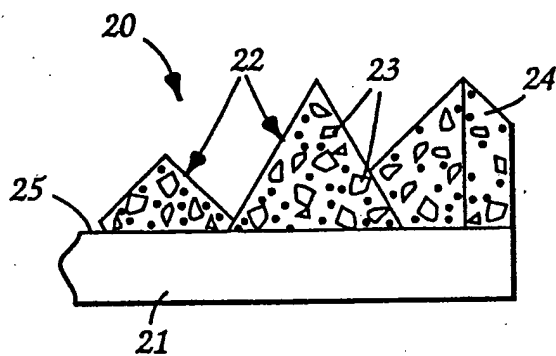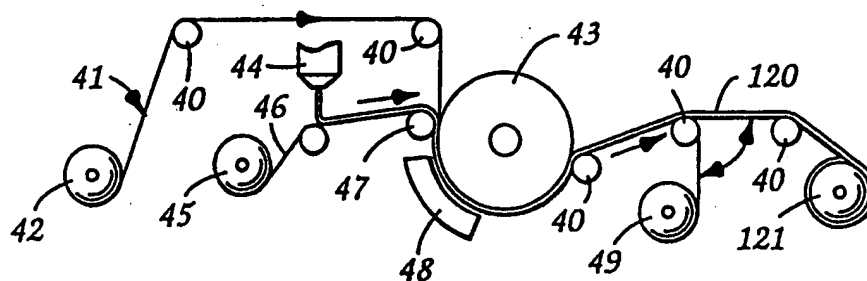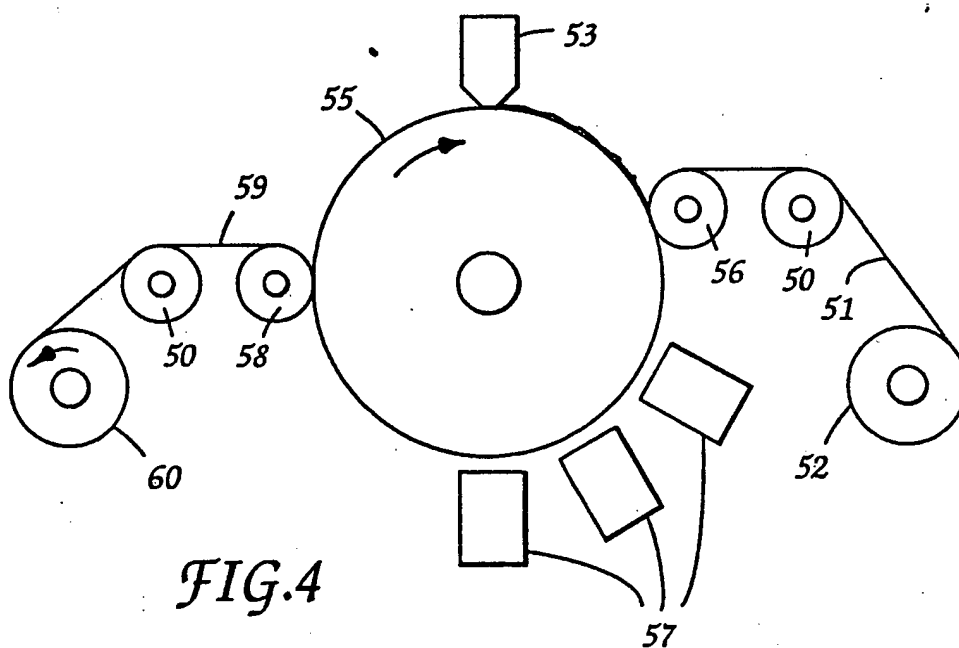
SUBSTITUTE SHEET (RULE 26)
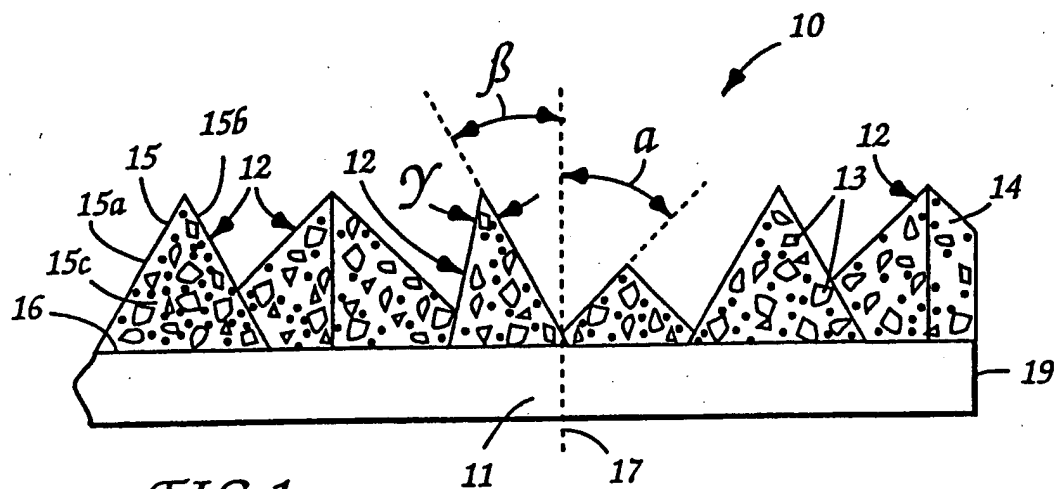
FIG.1

FIG.2

FIG.3

FIG.4

FIG.5

FIG.6

FIG.7
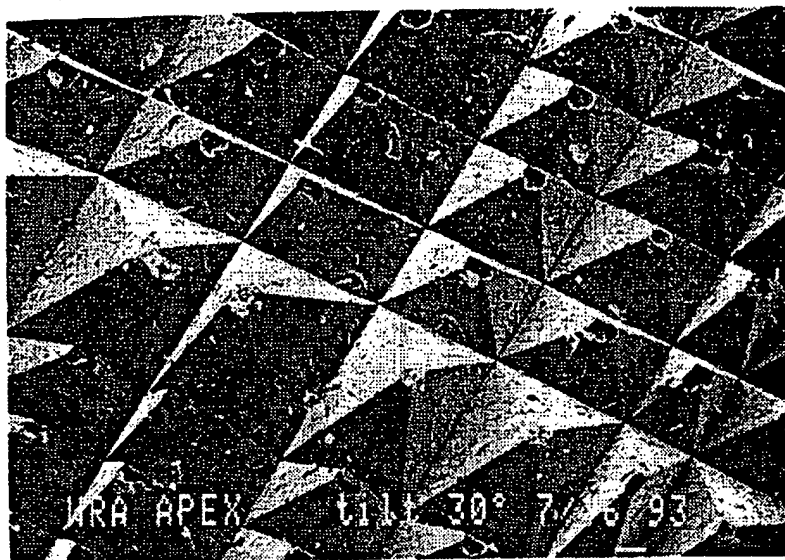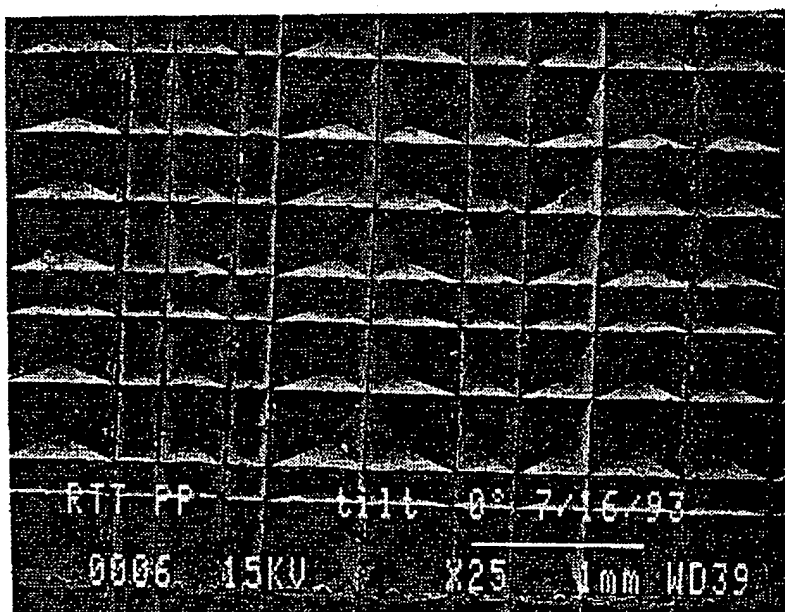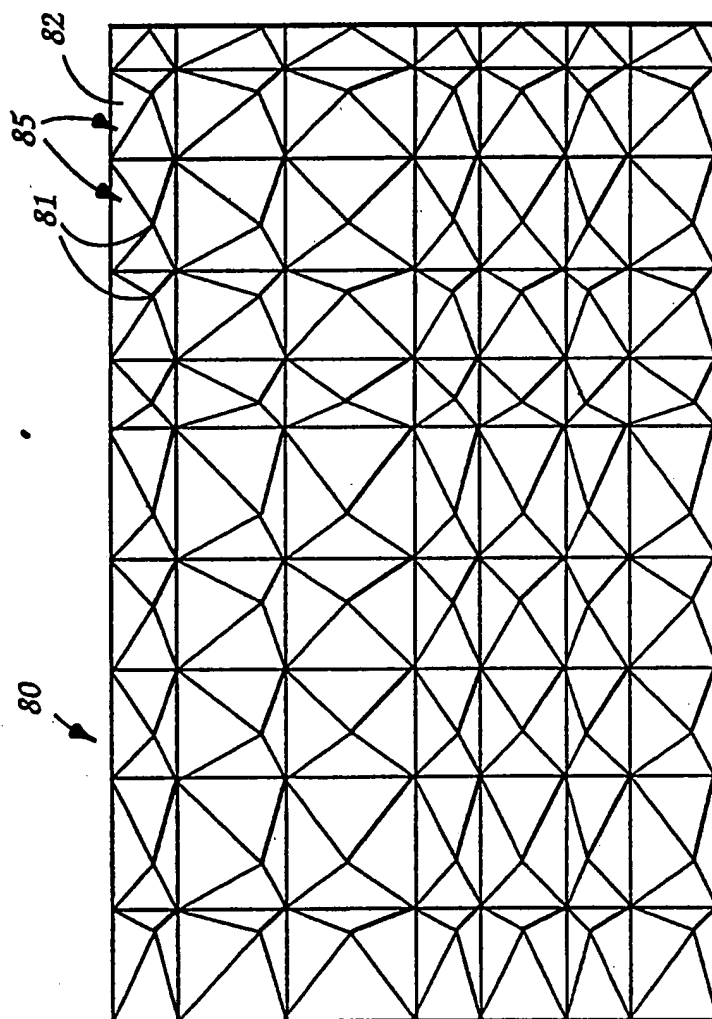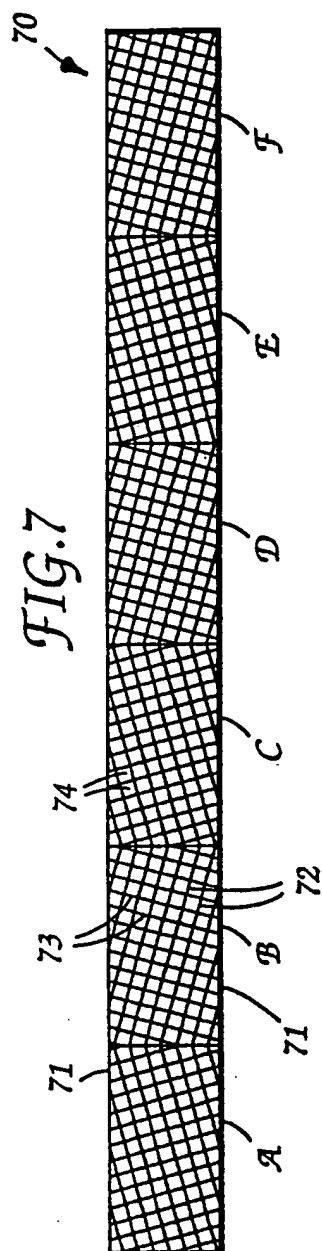
FIG.8

Inter   nal Application No
PCT/US 94/00754

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   B24D11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   B24D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO,A,92 13680 (3 M CO) 20 August 1992 cited in the application see the whole document -----	1,17,19

[ ] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
17 June 1994	0 1. 07. 94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL. - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Eschbach, D

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